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THE FUNDAMENTALS OF ELECTRODYNAMICS.*

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Statement of the Fundamental Equations.—The laws of electrodynamics are embodied in the well-known scheme of equations [1]

$$1/c(\rho\mathbf{u} + \partial\mathbf{E}/\partial t) = \text{curl } \mathbf{H}, \quad (1)$$

$$\rho = \text{div. } \mathbf{E}, \quad (2)$$

$$-\frac{1}{c}\frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}, \quad (3)$$

$$0 = \text{div. } \mathbf{H}, \quad (4)$$

together with a fifth relation whose aim is to describe the law of motion of an electron. This law states that the electron is a spherical shell of charge when viewed in a system of axes in which its center has zero velocity, and that in this system of axes, its acceleration and the other time derivatives of its motion are determined in such a manner that

$$\iiint \rho \mathbf{E} d\tau = 0. \quad (5)$$

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[1] The units here used are the Heavisidian units, in which the unit of charge and unit magnetic pole are respectively $1/\sqrt{4\pi}$ times the electrostatic and magnetostatic units.

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In the above equations, ρ is the charge density, $\mathbf{E}$ and $\mathbf{H}$ the magnetic field $\mathbf{u}$ the velocity, $d\tau$ an element of volume, and c a constant, which experiment shows to be equal to the velocity of light in vacuo.

It is customary to express (5) in another form. We first split the integral into two parts, one pertaining to the field $\mathbf{E}_i\mathbf{H}_i$, produced by the charge on the electron itself, disentangled from the total field in a manner to be explained later and the other, the field $\mathbf{E}_0$, $\mathbf{H}_0$, due to all the remaining charges of the system. Equation (5) may then be written

$$\int\int\int \rho \mathbf{E}_0 d\tau = -\int\int\int \rho \mathbf{E}_i d\tau. \tag{6}$$

It is possible to calculate $\mathbf{E}_i$ in terms of the acceleration $\ddot{\mathbf{S}}$, rate of charge of acceleration, $\dddot{\mathbf{S}}$, and higher time derivatives of the motion, so that expressing the right hand side of (6) in this way, the equation assumes the form

$$\int\int\int \rho \mathbf{E}_0 d\tau = \frac{e^2}{6\pi a c^2}\ddot{\mathbf{S}} - \frac{e^2}{6\pi c^3}\dddot{\mathbf{S}} + \cdots, \text{ etc.} \tag{7}$$

where a is the radius of the spherical shell, and e the electronic charge.

The left hand side of (7) being called the external force on the electron, the quantity $e^2/6\pi a c^2$, which is the coefficient of the acceleration on the right hand side is appropriately known as the mass of the electron, it being understood that (7) is applicable only to the case when the velocity of the electron is zero in the system of axes to which $\mathbf{E}$ and $\mathbf{H}$ are referred. In many cases it is customary to neglect altogether the terms on the right hand side of (7) other than the first, and to assume moreover that the external field is constant over the electron. In this case, (7) assumes the form

$$e\mathbf{E}_0 = e^2\ddot{\mathbf{S}}/6\pi a c^2. \tag{8}$$

In extending the law of motion of the electron to cases where the velocity of the electron is not zero in the system of axes in which $\mathbf{E}$ is measured, it is customary to invoke the assumption of the restricted theory of relativity which,

at any rate for the case where $\mathbf{E}_0$ and $\mathbf{H}_0$ may be assumed constant over the electron, leads via (7) to the result [2]

$$e\left(\mathbf{E}_0 + \frac{[\mathbf{w}\mathbf{H}_0]}{c}\right) = \frac{d}{dt}\left\{ m_0\mathbf{w} \Big/ \sqrt{1 - \frac{w^2}{c^2}} \right\}$$

$$+ \text{terms involving higher time derivatives} \quad (9)$$

where $m_0 = e^2/6\pi ac^2$, and w is the velocity of the center of the electron. For the case of an acceleration parallel to the velocity, the first term on the right hand side of (9) assumes the form $m_0\dot{\mathbf{w}}/(1 - w^2/c^2)^{3/2}$, and for the case of an acceleration perpendicular to the velocity it assumes the form $m_0\dot{\mathbf{w}}/(1 - w^2/c^2)^{1/2}$. We consequently speak of

$$\text{The Longitudinal Mass } \frac{e^2}{6\pi ac^2}\left(1 - \frac{w^2}{c^2}\right)^{-3/2},$$

and

$$\text{The Transverse Mass } \frac{e^2}{6\pi ac^2}\left(1 - \frac{w^2}{c^2}\right)^{-1/2}.$$

On the foregoing view, the quantity which is really measured when the mass is measured for small velocities is the quantity $e^2/6\pi ac^2$, and the value of a is then calculated as the radius of a sphere which would give rise to that mass.

Historical Survey.—At the time when Maxwell commenced his epoch making investigations the known laws of electrodynamics were summed up in conclusions which are the analytical equivalent of the following: [3]

$$4\pi I = \oint \mathbf{H}_s ds, \quad (10)$$

[2] If $\mathbf{E}_0$, $d\tau$, and $\mathbf{H}_0$ are not constant over the electron, the left-hand side of (9) would assume the form $\iiint \rho(\mathbf{E}_0 + [u\mathbf{H}_0]/c)d\tau$, but with the various elements of the integral calculated at different times.

[3] We are confining ourselves to the case of free æther, so that we use $\mathbf{H}$ instead of $\mathbf{B}$ in (11). The introduction of $\mathbf{B}$ and $\mathbf{D}$ into the discussion would carry with it more complexity of an irrelevant kind than is worth while for the purpose of the present historical survey. Our units are here, of course, the ordinary electromagnetic units, since the introduction of Heavisidean here would add needlessly to the apparent artificiality of the equations of the pre-Maxwell period.

expressing the fact that the line integral of the magnetic field around a closed circuit encircling a current I is equal to $4\pi I$.

Then we have the relation

$$\frac{-d}{dt}\int\int \mathbf{H}_n dS = \oint \mathbf{E}_s ds, \tag{11}$$

expressing Faraday's law, that the rate of change of the surface integral of the normal component $\mathbf{H}_n$ of the magnetic field taken all over a cap bounded by a circuit is equal to the negative of the line integral of the electric field taken all around the circuit. Finally we have a law having to do with the mechanical forces on a circuit carrying a current, and equivalent to the statement that in the case of a number of circuits expressed by generalized coördinates q_r, the generalized force F_r necessary to hold the circuit in position against the actions of the other circuit is [4]

$$F_r = I_r \frac{\partial}{\partial q_r}\int\int_r \mathbf{H}_n dS. \tag{12}$$

The negative of this quantity, $f_r(= -F_r)$ is the generalized force on the circuit due to the other circuits, so that:

$$f_r = -I_r \frac{\partial}{\partial q_r}\int\int \mathbf{H}_n dS, \tag{13}$$

which is the form in which the expression is usually thought of.

Equation (13) is of course the analytical equivalent of the law obtained by calculating the forces between the current circuits by treating them in terms of their equivalent shells, and it is also the analytical equivalent of the statement that the forces on a current circuit as a whole, due to the other circuits is the same as that obtained by attaching to each element of length ds of the conductor a force δf_r, given by

$$\delta f_r = [I_r \cdot \mathbf{H}]\delta s. \tag{14}$$

[4] The directions are such that viewing the circuit from that side from which the current appears to flow counter-clockwise, the positive direction of the normal is drawn from the observer through the cap.

Maxwell set himself the task of moulding equations (11) and (12) into a form which made them appear as the outcome of general dynamical laws.

In the hands of Maxwell, equation (10) amounted practically to a definition of **H** in terms of the currents. It is not difficult to show that (10) contains as an analytical consequence, that insofar as **H** is determined by the current alone, the flux of **H** through any circuit denoted by subscript r, is given by

$$\int\int \mathbf{H}_n dS = L_{1r}I_1 + L_{2r}I_2 + \cdots L_{rr}I_r, \qquad (15)$$

where the L's are the ordinary coefficients of self and mutual induction, and are perfectly definite functions of the geometry of the system, given by

$$L_{mn} = \int\int \frac{\cos\varphi ds_m ds_n}{r}, \qquad (16)$$

φ being the angle between the elements ds_m and ds_n of the circuits concerned.

Thus, Faraday's law (11), for the circuit r becomes

$$-\frac{d}{dt}(L_{1r}I_1 + L_{2r}I_2 + \cdots L_{rr}I_r) = p_r, \qquad (17)$$

where p is the electromotive force $\left(= \int \mathbf{E}_s ds\right)$ produced in the circuit as a result of the varying currents in that circuit and the other circuits. Or, if $P_r = -P_r$ is the generalized *external* force necessary to result in the condition of changing currents in the circuit r.

$$\frac{d}{dt}(L_{1r}I_1 + L_{2r}I_2 + \cdots L_{rr}I_r) = P_r. \qquad (18)$$

Again, the law (12) for the generalized force acting on the circuit r becomes [5]

$$F_r = I_r\left(I_1\frac{\partial L_{ir}}{\partial q_r} + I_2\frac{\partial L_{2r}}{\partial q_r} + \cdots I_r\frac{\partial L_{rr}}{\partial q_r}\right). \qquad (19)$$

[5] Of course, $\partial L_{rr}/\partial q_r$ is zero, and is merely included for symmetry.

Thus the problem is to represent (18) and (19) as a consequence of generalized dynamics. The procedure is now almost obvious. Lagrange's equations for generalized coordinates are of the form:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_m}\right) - \frac{\partial T}{\partial q_m} = \Phi_m, \tag{20}$$

where Φ_m is the generalized force associated with the coordinates q_m. Suppose, in addition to the mechanical coordinates q_m, we think of electrical coördinates which we shall make appear only in our kinetic energy function through their velocities, which we shall associate with the various currents I_1, I_2, $\cdots$. Suppose in fact, we take for T the expression:

$$T = \tfrac{1}{2}L_{11}I_2^2 + L_{12}I_1I_2 + L_{13}I_1I_3 + \cdots \tfrac{1}{2}L_{22}I_2^2 + L_{23}I_2I_3 + L_{24}I_2I_4 + \cdots \text{etc.} + T_m, \tag{21}$$

where T_m is the expression we should have for the kinetic energy of the matter of the wires in the absence of any currents. Then, applying Lagrange's equations to the electrical coördinate represented as regards its velocity by I_r, we obtain (since T does not involve the electrical coördinates)

$$\frac{d}{dt}(L_{1r}I_i + L_{2r}I_2 + \cdots) = P_r, \tag{22}$$

which is the same as (18), the equivalent of the Faraday law. And, by applying the equations to the mechanical coördinate q_r, we obtain

$$I_r\left(I_1\frac{\partial L_{1r}}{\partial q_r} + I\frac{\partial L_{2r}}{\partial q_r} + \cdots I_r\frac{\partial L_{rr}}{\partial q_r}\right) + \frac{d}{dt}\left(\frac{\partial T_m}{\partial \dot{q}_r}\right) - \frac{\partial T_m}{\partial q_r} = \Phi_r. \tag{23}$$

The part involving T_m is simply the part of Φ_r necessary to accelerate the brute matter of the conductors. In the case where the conductors are held fixed, Φ_r represents what we have called F_r and (23) becomes

$$I_r\left(I_i\frac{\partial L_{ir}}{\partial q_r} + I_2\frac{\partial L_{2r}}{\partial q_r} + \cdots I_r\frac{\partial L_{rr}}{\partial q_r}\right) = F_r, \tag{24}$$

which is the same as our law (18), which is the equivalent of (12).

We may regard the achievement of Maxwell as that of finding the necessary expression for T to permit of the moulding of the equations into the dynamical form in the sense we have described.

Maxwell next endeavored to extend the theory to open circuits, and to the motion of charges. Writing (10) in differential form it becomes

$$4\pi\mathbf{i} = \text{curl } \mathbf{H}, \tag{25}$$

where $\mathbf{i}$ is now the current density, it being understood, however, that the stream lines of the flow continue themselves into a complete circuit.

The thought is that $\mathbf{i}$ may be regarded as a flow of some density with a velocity $\mathbf{u}$, and that we may be able to write

$$\frac{4\pi\rho\mathbf{u}}{c} = \text{curl } \mathbf{H}. \tag{26}$$

The factor c is included because, if ρ is in electrostatic units, our thought of the similarity between what has been called current density and $\rho\mathbf{u}$ has implied only a proportionality between $\rho\mathbf{u}$ and $\mathbf{i}$, since the unit of $\mathbf{i}$ in equation (25) has been chosen so that $\mathbf{H}$ shall represent the force on unit pole in such cases where that test is applicable. c is in fact, the ratio of the electrostatic to the electromagnetic unit of charge.

With equation (26) however, we immediately encounter a difficulty; for, since div. curl $\mathbf{H} = 0$, that equation would imply

$$\text{div. } \rho\mathbf{u} = 0.$$

But, if we are to regard electricity in the light of an indestructible entity, its motion must be controlled by the equation of continuity

$$\text{div. } \rho\mathbf{u} + \frac{\partial\rho}{\partial t} = 0, \tag{27}$$

so that (26) must be regarded as impossible for even such a simple case as that of a moving charge of finite spacial extent, since here the density at any point changes with the time.

In order to escape this difficulty, Maxwell generalized (26), which is strictly true only when $\partial\rho/\partial t = 0$, to the equation

$$\frac{4\pi}{c}(\rho\mathbf{u}) + \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} = \text{curl } \mathbf{H}, \tag{28}$$

which, on taking the divergence of both sides gives

$$4\pi \text{ div. } \rho\mathbf{u} + \frac{\partial}{\partial t}\text{div. } \mathbf{E} = 0 \tag{29}$$

so that, provided that

$$4\pi\rho = \text{div. } \mathbf{E} \tag{30}$$

(29) becomes

$$\text{div. } (\rho\mathbf{u}) + \frac{\partial \rho}{\partial t} = 0$$

so that the situation is now consistent with the equation of continuity.[6]

The quantity $\mathbf{E}$ occurring in (30) is of course, measured in electrostatic units, while the $\mathbf{E}$ in (11) is associated with a current I measured in the same units as are employed in (10). Hence, if $\mathbf{E}$ is to be in electrostatic units, we must divide the left-hand side of (11) by c; and, expressed in differential form, and applied to a fixed circuit of infinitesimal dimensions, the equation would then become

$$-\frac{1}{c}\frac{\partial \mathbf{H}}{\partial t} = \text{curl } \mathbf{E}. \tag{31}$$

It will here be noted that we have a partial time derivative in place of the total time derivative of (11) which latter equation is applicable to a moving circuit as well as to a fixed one.

Equation (14), with the current (there in electromagnetic units) regarded in the light of a generalization to moving charge density becomes the equivalent of stating that the force per unit volume on the electricity moving with velocity

[6] The generalization on (26) implied in the addition of the term involving $\partial\mathbf{E}/\partial t$, is of course not the only one possible. We might add *in addition* any vector whose divergence was zero without violating (27).

$\mathbf{u}$ is $\rho[\mathbf{u}\cdot\mathbf{H}]/c$, the c being introduced because ρ is in electrostatic units. If we introduce the further idea that, in the presence of an electric field $\mathbf{E}$ there would be a force per unit volume equal to $\mathbf{E}\rho$,[7] $\rho[\mathbf{u}\cdot\mathbf{H}]/c$ the total force per unit charge would be

$$\text{Force per unit charge} = \mathbf{E} + \frac{[\mathbf{uH}]}{c}. \tag{32}$$

If we take a new unit of charge strength and a new unit of magnetic pole strength each respectively $1/\sqrt{4\pi}$ of the electrostatic and magnetostatic units, and if the fields $\mathbf{E}$ and $\mathbf{H}$ be defined as the forces on these units, the 4π disappears, as is well known from (28) and (30), and our equations become

$$1/c\left(\rho\mathbf{u} + \frac{\partial\mathbf{E}}{\partial t}\right) = \text{curl } \mathbf{H}, \tag{33}$$

$$\rho = \text{div. } \mathbf{E}, \tag{34}$$

$$-\frac{1}{c}\frac{\partial\mathbf{H}}{\partial t} = \text{curl } \mathbf{E}, \tag{35}$$

$$0 = \text{div. } \mathbf{H}. \tag{36}$$

$$\text{Force per unit charge} = \mathbf{E} + \frac{[\mathbf{uH}]}{c}. \tag{37}$$

The addition of the equations $0 = \text{div. } \mathbf{H}$ implies the additional postulate that all magnetic fields are traceable to currents without the invocation of any magnetic poles.

The foregoing arguments can hardly be regarded as a proof of the relations (33)–(37). As we have already remarked, the generalization involved in the addition of the term involving $\partial\mathbf{E}/\partial t$ in (33) could have been made in an infinite number of other ways as far as serving the purpose of providing for the equation of continuity is concerned. Again, the deduction of (35) as applied to the field at a point in space from the (11) as applied to a complete material circuit is not an entirely rigorous procedure. Similar remarks may

[7] This is not a foregone conclusion, because even in the sense of the definition of $\mathbf{E}$ in terms of the force on a charge, that charge is supposed at rest.

be made regarding (37). Moreover, the sense in which the term "force" is considered as applying in equations (37) is to some extent vague when considered in relation to distributions of electricity, for the scheme of equations itself provides no idea of electric mass to combine with acceleration as a criterion for a realization of the actions of the so-called force.

The best that can be said for the differential forms of the equations in the light in which they have thus been obtained is that they are forms which when applied to the large scale phenomena of wire circuits, reproduce the equations (10) and (11). And even this statement is not correct except for steady currents for equation (10) contains no $\partial \mathbf{E}/\partial t$ term. It is quite true that the scheme represented by (10), (11), and (12), together with its moulding into a dynamical form as carried out by Maxwell represents a logical scheme which might have corresponded to nature even for varying currents. There are no inconsistencies in the scheme itself. The extension to the general case of moving charges has, however, necessitated the introduction of the $\partial \mathbf{E}/\partial t$ term; and, this term having been introduced, it must not be discarded on return to the simpler case of closed circuits unless it, of its own accord, disappears for that case, and this it does not do.

Maxwell was not satisfied with a mere deduction of (35) by the process we have sketched; but, having modified (26) by the introduction of the $\partial \mathbf{E}/\partial t$ term, he proceeded to seek an expression for the kinetic and potential energies per unit volume in terms of the electric fields and the current densities, which, by the application of the dynamical equations for continuous media should result in equations (33)–(37), in a manner analogous to that which he had adopted for the case of continuous circuits. His analysis suffered from certain imperfections, and it was later modified by Lorentz, Larmor, and others, with the special additional postulate that the electricity existed in the form of definite entities or electrons. The procedure amounted to choosing an expression for the kinetic and potential energies per unit volume of the medium as a function of the electric field and motion of the electricity, and then by means of the Hamiltonian dynamical principle

$\delta \int (T - V)dt = 0$ applied to these energy expressions deducing two sets of equations, one of which was the equivalent of (35), and the other the equivalent of (37), but in a more unambiguous form. The form in question stated that the electron moves in such a manner that

$$\int\int\int \left(\mathbf{E} + \frac{[\mathbf{uH}]}{c} \right) \rho d\tau = 0, \tag{38}$$

the integral being taken over the electron and the fields representing the total fields, including the parts produced by the electron itself.

Again, these derivations can hardly be regarded as having accomplished more than the finding of the expressions which it is appropriate to call kinetic and potential energy in order that the customary dynamical procedure shall lead to the equations desired.

As a matter of fact, the form of the force equation symbolized in (38) is one which would be inconsistent with the principle of relativity; for, in the manner which it is presented by the dynamical development, it is of course not restricted to the case where the electron is momentarily at rest in the system of axes to which **E** and **H** are referred.

We shall presently return to another form of the expression of the dynamics of the electron, and one which is consistent with the theory of relativity; but for the moment, it will be well to make a digression to discuss a few matters concerned with the significance of (1)–(4), quite apart from the question of their origin.

The Significance of the Circuital Relations.—In the first place it is to be remarked that while equations (1)–(4) may be solved so as to give the fields **E** and **H** in terms of ρ and $\rho\mathbf{u}$ supposed assigned, they tell us nothing about the motions of the charges themselves. Since the equations are linear, we may add any two solutions and obtain as a result another solution. Thus, if we should find, as is in fact quite easy to do, the solution for the fields of an electron moving in a straight line with velocity v, and add to this the solution for another electron moving towards the first with velocity v,

and then add the solutions, the result would also satisfy the equations. The equations themselves would be perfectly content for the electrons to go on in their motions quite oblivious of each other's presence. It is to the force equation entirely that we must look for an answer to how the motions of the electron influence each other. Had equations (1)–(4) been non-linear, this conclusion would not have held, solutions would not have been additive to give another solution; and, the equations themselves would have had something to say about the motions of the electrons relative to each other.

We frequently hear difficulties raised as to how the electron holds together, in view of the repulsion of its individual parts. Logically there is no difficulty. Equations (1)–(4) are perfectly content to have the various parts of an electron in mutual proximity without any tendency to fly apart. Even the force equations concern only the motion of the electron as a whole; and it is no quibble to maintain that the ideas applicable to the whole entity are not applicable to its individual parts; for, as a matter of fact, even equation (38) while implying a motion of the electron which secures a zero value for $\int\int\int (\mathbf{E} + [\mathbf{uH}]/c)\rho d\tau$, by no means provides for the vector $\mathbf{E} + [\mathbf{uH}]/c$ being zero at each element of volume.

Solution of the Equations.—It is possible to solve equations (1)–(4) in such manner as to obtain the field $\mathbf{E}$, $\mathbf{H}$, in terms of the charge density ρ, and the product $\rho\mathbf{u}$ supposed assigned. The results are:

$$\mathbf{E} = -\frac{1}{c}\frac{\partial \mathbf{U}}{\partial t} - \text{grad. } \varphi, \tag{39}$$

$$\mathbf{H} = \text{curl } \mathbf{U}, \tag{40}$$

where

$$4\pi c\mathbf{U} = \int\int\int \frac{(\rho\mathbf{u})}{r}\, d\tau, \tag{41}$$

$$4\pi\varphi = \int\int\int \frac{(\rho)}{r}\, d\tau, \tag{42}$$

and where $\mathbf{U}$ and φ are still further subjected to the condition

that

$$\text{div. } \mathbf{U} = -\frac{1}{c}\frac{\partial \varphi}{\partial t}. \qquad (43)$$

The integrals are supposed taken throughout all space, and the parentheses are intended to denote that in finding the values of $\mathbf{U}$ and φ at time t, at any point (which is momentarily taken as the origin) we must insert in any particular element of volume the values of ρu or ρ not at the time t, but at the earlier time $t - r/c$.[8]

Equations (1) and (2) of course contain the equation of continuity as a consequence. It can readily be shown that the relation (43) is the analytical guardian of the equation of continuity in preventing us from assigning in (41) and (42), values of $\rho\mathbf{u}$ and ρ which would of themselves violate that condition.

Thus, for example, if we were to assign $\mathbf{u} = 0$, and $\rho = f(r)e^{-\alpha t}$, our assignment would of itself be inconsistent with

$$\text{div. } \rho\mathbf{u} + \frac{\partial \rho}{\partial t} = 0.$$

Equations (43) would prevent such an assignment of ρ and $\rho\mathbf{u}$.

The fact that the solutions represent φ and $\mathbf{U}$ and so $\mathbf{E}$ and $\mathbf{H}$ as the sum of a number of parts, each determined independently by the separate elements of charge enables us to speak of the field contributed by a charge A as distinct from the field contributed by some other charge B. Had, for example, products of the values of $\rho\mathbf{u}$ in the different elements of volume been involved in the expression for the field at a point, it would have been impossible to speak of a part of the field being due to one charge and part to another.

Definitions.—Before proceeding further, it is well that we pause for a moment to consider the significance which is to be attached to quantities like $\mathbf{E}$ and $\mathbf{H}$ in a scale of analysis which is contemplated in the equations as they are used in atomic physics. The definition of the magnetic field as the force on a unit magnetic pole, and of the electric field as the

[8] We shall not pause to consider the possibilities inherent in the use of the advanced potentials.

force on unit charge, are permissible so long as we are dealing with large scale phenomena; but, a unit pole has only existence in a macroscopic sense where a point is identified in a crude way with a region sufficiently large to contain many molecules. Even though, in the case of the charge, we can go to as small a unit as the electron, at any rate in imagination, for a charge entity in terms of which to define, by the magnitude of its acceleration, the electric field, our procedure becomes illogical when we contemplate a situation in which the field **E** varies enormously in magnitude and direction over the space comprised by a single electron. The question here involved is not one of experimental difficulty, but of logical meaninglessness. It is not one purely ideal in its character, moreover; for in one of the most important applications of the equations, that involved in finding the quantity represented by the right-hand side of (6), we encounter a situation in which the quantity **E** with which we deal, varies to the extent of the whole of its value over the electron.

Why is it that we are not led into hopeless error in cases of the above kind? It is because we do not *use* **E** and **H** in the sense of the definition in terms of unit charges and unit magnetic poles.

If we examine what we actually do in all problems of atomic dimensions, we shall find that the starting point is the *assignment* of the charges and of their motions—the assignment of ρ and $\rho\mathbf{u}$. This is followed by the *calculation* of **E** and **H** by aid of equations (39)–(42), and the subsequent utilization of the same **E** and **H** for some specific purpose, as, for example, the determination of the integral on the right-hand side of (6) (where only **E** is required however).

From the standpoint which is the standpoint of their actual use in nearly all problems of atomic importance, equations (1)–(4) really constitute the *definitions* of **E** and **H** in terms of ρ and $\rho\mathbf{u}$ supposed assigned.

But you may well ask what we gain by mere definition. We cannot discover laws of physics by definitions. That is true; but, we can, by well chosen definitions insure useful properties for the quantities defined. Thus, the quantities **E** and **H** defined by equations (1)–(4) vary with space and

time in free space in accordance with the wave equations. Thus, for example:

$$\nabla^2\mathbf{E} - \frac{1}{c^2}\frac{\partial^2\mathbf{E}}{\partial t^2} = 0$$

and the wave equation insures for them certain other important properties—such, for example, as the property that in a plane wave the vectors **E** and **H** are perpendicular to each other, and lie on the plane of the wave-front. It would be useless to define things like **E** and **H** if we could not express in terms of them the behavior of something we can observe. The justification for their definition in electrodynamics lies in their being appropriate quantities in terms of which to express the motions of electrons through such equations as (6), or (9), for example; and, the properties provided for in their definitions provide in turn for properties which we can observe in the motions of the electrons referred to. Now it is quite true that, in the majority of problems of atomic dynamics, the things which happen to electrons do not go on in such manner as to indicate that they have been controlled by the force equation. Nevertheless, in formulating the new laws of such a phenomenon as the photoelectric effect, for example, the properties of **E** and **H** inherent in their definitions through the electromagnetic equations make them useful props in a scaffolding appropriate to the new theory.

All that we need as a basis in terms of which to define a set of electromagnetic vectors satisfying equations (1)–(4) is a quantity ρ and a quantity $\rho\mathbf{u}$ satisfying the equation of continuity

$$\text{div. } \rho\mathbf{u} + \frac{\partial\rho}{\partial t} = 0.$$

As a matter of fact, the density and density times velocity occur in the solutions for φ and **U**, and so in those for **E** and **H** in the forms they do, not because of any property inherent in themselves, but simply on account of their relative positions in (1)–(4). If we should replace ρu_x, ρu_y, ρu_z, ρ by any four quantities $\mathbf{S}_x$, $\mathbf{S}_y$, $\mathbf{S}_z$, **R**, satisfying

$$\text{div. } \mathbf{S} + \frac{\partial\mathbf{R}}{\partial t} = 0,$$

the solutions would be of exactly the same form as before, with **S** and **R** replacing $\rho\mathbf{u}$ and ρ.

In Schrödinger's theory of atomic structure, at any rate in its original aspect in which he seeks to account for the frequencies emitted by an atom, the aim is to get a quantity which he calls $\psi\bar{\psi}$, varying with x, y, z, and varying everywhere with time in a manner composed of the simple harmonic frequencies desired. The nature of $\psi\bar{\psi}$ turns out to be such that when integrated throughout space, the result is constant with time. Hence, defining **u** by the relation

$$\psi\bar{\psi}\cdot\mathbf{u} = -\frac{1}{4\pi}\,\mathrm{grad}\int\int\int\frac{1}{r}\cdot\frac{\partial\psi\bar{\psi}}{\partial t}\,d\tau,$$

we insure that

$$\mathrm{div.}\,(\psi\bar{\psi}\cdot\mathbf{u}) + \frac{\partial\psi\bar{\psi}}{\partial t} = 0, \qquad (44)$$

so that $\psi\bar{\psi}$ satisfies the equation of continuity. Moreover, integrating throughout space

$$\partial/\partial t\int\int\int\psi\bar{\psi}d\tau = -\int\int\int\mathrm{div.}\,\psi\bar{\psi}\mathbf{u}d\tau$$

$$= -\int\int\psi\bar{\psi}u_n dS, \qquad (45)$$

the surface being supposed at infinity.

Since $\int\int\int\psi\bar{\psi}d\tau$ is constant, $\int\int\psi\bar{\psi}\mathbf{u}_n dS = 0$. Had this not been the case, our adjustment of **u** to satisfy (44) would have involved us in a flow through the infinite boundary, a circumstance which would have involved us in logical difficulties into which we need not enter further here.

The equation of continuity having been provided for, the quantities $\psi\bar{\psi}$ and $\psi\bar{\psi}\cdot u$ provide suitable quantities in terms of which to define a set of vectors **E** and **H**, satisfying equations of the type (1)–(4), in terms of which the action of radiation on some other atom may be discussed.

By proceeding to the limiting case for a doublet M in electromagnetic theory, we find that φ and **U**, and so **E** and **H** are completely determined by the assignment of **M** and $\dot{\mathbf{M}}$, so that any quantity **M** varying with time and assigned

to a particular point of space may be used as a basis for defining a set of electromagnetic vectors conforming to the frequencies contained in the time variations in **M**. In some cases of modern atomic theory where there are several dimensions, the nature of the $\psi\bar{\psi}$ function referred to above is such that the quantity is expressed as a function of more than 3 coördinates, and consequently it cannot immediately be assigned to any particular point in space. Nevertheless, the process adopted in integrating throughout the multidimensional space for the purpose of finding what Schrödinger refers to as the moment, does lead to a definite number for the atom, a number, moreover, having in its time variations the frequencies desired; and, this number with its time rate of change may be used as a means of defining a set of electromagnetic vectors as before. The argument in the multidimensional space assigns no position to this moment in the multidimensional space, but on the other hand, it has no power to prevent our assigning to it any position we choose.

It is true that, in the more recent developments of Heisenberg and others, we have come to regard the $\psi\bar{\psi}$ function in a light different from that implied above. Nevertheless, the illustration we have given serves to indicate the sort of position which the electromagnetic equations may occupy in developments of modern atomic dynamics.

The vectors **E** and **H** having been provided for in some such manner as the foregoing, we may then proceed to calculate their values at other points in space where we wish to discuss some phenomenon such as the Compton effect, for example. It is then in terms of these vectors **E** and **H**, that we discuss the phenomenon; not by their action in the sense of the old force equation of electrodynamics, but usually in their modification of some Hamiltonian form which is to be used as the basis of the theory under consideration.

Definitions in Terms of Assigned Entities.—For one to whom the aspect of (1)–(4) as definitions of **E** and **H** is too artificial for his mental satisfaction, and who insists upon definitions of **E** and **H** in terms of the supposed action of these vectors on something or other, a way is still open, at least to a scale of precision which regards the electron as no more than a point entity. It is only at the expense of

considerable complication, however, that this way can be made precise.

The most drastic change from the classical procedure must be made in the matter of the magnetic pole. And, as is often the case, if we follow the plan of what actually happens in nature rather than invent artificial concepts, we gain in the long run. The action of a magnetic field on a pole is an idealization of its action on a magnet, and that is an idealization of the really more simple concept of its action on a moving electron, since the motions of electrons endow the magnet with its magnetic properties. It is then in the spirit of its action on a moving electron that we shall seek to define our magnetic field.

Let us suppose for a moment, that $\mathbf{E}$ and $\mathbf{H}$ had been defined in a manner which for the moment we need not specify, and let us suppose that the motion of an electron in terms of the fields so defined were given by (9), where we shall suppose the terms on the right-hand side other than the first to be absent. Then, by putting $w = 0$, it would be a fact that

$$\mathbf{E}_0 = \frac{m_0}{e} \underset{w=0}{L_t} \frac{d}{dt} \frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}} \tag{46}$$

and that when w was not zero,

$$\frac{[\mathbf{w}\mathbf{H}_0]}{c} = \frac{m_0}{e} \left\{ \left(\frac{d}{dt} \frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}} \right)_{w \neq 0} - \underset{w=0}{L_t} \frac{dt}{dt} \frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}} \right\}. \tag{47}$$

If the direction of $\mathbf{w}$ be adjusted so that the quantity on the right-hand side is a maximum, we shall have

$$\frac{\mathbf{H}_0}{c} = \frac{m_0}{ew} \left\{ \left(\frac{d}{dt} \frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}} \right)_{w \neq 0} - \underset{w=0}{L_t} \frac{d}{dt} \frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}} \right\}, \tag{48}$$

where the $\mathbf{w}$ inserted is chosen in the direction to make $\mathbf{H}_0$ a maximum. The direction of $\mathbf{H}_0$ is that consistent with the vector product of $\mathbf{H}_0$ and the velocity $\mathbf{w}$ being in the direction of the vector specified as the right-hand side of (47).

Now the facts embodied in the above equations provide us with a means of defining $\mathbf{E}_0$ and $\mathbf{H}_0$. For, suppose,

discarding the fact that $\mathbf{E}_0$ and $\mathbf{H}_0$ were supposed defined originally, we take (46) as a definition of $\mathbf{E}_0$; and, after proceeding to the limit when $w = 0$ in order to secure uniqueness, suppose we take (48) as the basis of our definition of $\mathbf{H}_0$. That is:

$$\frac{\mathbf{H}_0}{c} = \frac{m_0}{e} \underset{w=0}{L_t} \frac{\left[\left(\frac{d}{dt}\frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}}\right)_{w\neq 0} - \underset{w=0}{L_t}\frac{d}{dt}\frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}}\right]}{w}. \quad (49)$$

Then, the definitions so found will be consistent with the equation

$$e\left(\mathbf{E}_0 + \frac{[\mathbf{w}\mathbf{H}_0]}{c}\right) = \frac{d}{dt}\frac{m_0\mathbf{w}}{\sqrt{1 - w^2/c^2}} \quad (50)$$

for all values of $\mathbf{w}$. Of course, they would not *necessitate* that (50) should hold for all values of $\mathbf{w}$.

If it did not turn out that (50) were true for all values of $\mathbf{w}$ when $\mathbf{E}_0$ and $\mathbf{H}_0$ were defined in terms of its limiting value, our definitions would be definite, at least, apart from further criticisms which I shall presently raise, but they would be useless. It would then be necessary to find in place of $\frac{d}{dt}\frac{m_0\mathbf{w}}{\sqrt{1 - w^2/c^2}}$ a quantity $\mathbf{W}$ which, when we again made our definitions in a manner analogous to the above, gave us quantities $\mathbf{E}_0$ and $\mathbf{H}_0$, which were consistent with

$$e\left(\mathbf{E}_0 + \frac{[\mathbf{w}\mathbf{H}_0]}{c}\right) = \mathbf{W} \quad (51)$$

for all values of $\mathbf{w}$.

Of course, it will be understood that our experimental realization of the above definitions would involve the measurement of such quantities as $\underset{w=0}{L_t}\frac{d}{dt}\frac{\mathbf{w}}{\sqrt{1 - w^2/c^2}}$, a more or less ideal experiment. In the case cited, we should have nothing but an acceleration to measure; but in general, this would not be the case. Thus, to take an example, suppose there existed certain quantities $\mathbf{E}_0$ and $\mathbf{H}_0$ in terms of which the equation of motion of the electron was

$$e\left(E_0 + \frac{[\mathbf{w}\mathbf{H}_0]}{c}\right) = a_0\ddot{\mathbf{S}} + a_1\dddot{\mathbf{S}} + a_2\ddddot{\mathbf{S}} + \cdots, \quad (52)$$

where $\ddot{\mathbf{S}}$ represents the acceleration, and the a's are functions of the velocity. On putting $\mathbf{w} = 0$, we obtain

$$e\mathbf{E}_0 = \bar{a}_0\ddot{\mathbf{S}} + \bar{a}_1\dddot{\mathbf{S}} + \bar{a}_2\ddddot{\mathbf{S}} + \cdots, \tag{53}$$

where the $\bar{a}$'s are the limiting values of the a's for zero velocity. We see that, in order to complete our definition it would be necessary to specify $\dddot{\mathbf{S}}$, $\ddddot{\mathbf{S}}$, $\cdots$, etc., when $w = 0$. Moreover, we cannot specify these arbitrarily. For example, we cannot say "consider an electron for which the velocity is zero and all the time derivatives of the motion are zero except $\ddot{\mathbf{S}}$, because, although $\ddot{\mathbf{S}}$ could adjust itself so that $e\mathbf{E}_0 = \bar{a}_0\ddot{\mathbf{S}}$ at the instant chosen, it would have to be in the process of change in order to make (52) fit the possibly new value of $\mathbf{E}_0$, and of $\mathbf{H}_0$ and $\mathbf{w}$ at the next and subsequent instants. Our only hope, in the case of such a situation as is represented in (53) would be, having made a satisfactory guess at the final form (52), to proceed to its limiting case (53), and then define $\mathbf{E}_0$ in terms of the actual values of $\ddot{S}$, $\dddot{S}$, etc., as measured for that case.[9]

The Relativity Dynamics of the Electron.—Although the recent developments of the quantum theory have rendered it necessary for us to change our ideas as to the motion of an electron, and to discard completely the older force equations of electrodynamics as representative of the laws of motion of the electron, nevertheless the fact that classical laws do hold in limiting cases of slowly varying forces causes them still to form an important part in the dynamic story of atomic processes. And, possibly on account of the primitive stages of development of the modern theories, certain of the expressions of classical theory do play a part, and an important part, in building up the detailed laws of quantum mechanics.

In our modern representation of the classical theory we pay little attention to such concepts as the electrons moving in such a way as to satisfy (38), but place more weight on the relativity theory as a guide.

[9] Even here, it is not obvious that there would be a unique set of values of the time derivatives of S for a given value of $\mathbf{E}_0$, independently of the way in which $\mathbf{E}_0$ was changing with the time. However, we here enter upon the whole question of the possibility of an expression of the type (52) as representing the motion of an electron.

In ordinary general dynamics, the equation of motion of a system may be written in the form of Lagrange's equation

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_r}\right) - \frac{\partial L}{\partial q_r} = 0. \tag{54}$$

Here no restriction is placed on L, other than the restriction that it is a function of the coördinates and the generalized velocities, and possibly also of the time. (54) is the analytical equivalent of

$$\delta \int L dt = 0, \tag{55}$$

where the values of δq_r at the time limits are zero. (54) contains as a consequence

$$\frac{d}{dt}\left\{ \Sigma \dot{q}_r \frac{\partial L}{\partial \dot{q}_r} - L \right\} + \frac{\partial L}{\partial t} = 0. \tag{56}$$

If $L = T - V$ and T is a homogeneous quadratic function of the time rates of change of the coördinates, while V is a function of the coördinates and time, it is easy to show that

$$\Sigma \dot{q}_r \frac{\partial L}{\partial \dot{q}_r} = 2T$$

and equation (56) becomes

$$\frac{d}{dt}(T + V) + \frac{\partial L}{\partial t} = 0,$$

so that if V does not involve the time explicitly

$$\frac{d}{dt}(T + V) = 0$$

and

$$T + V = \text{constant}$$

$T + V$ is of course the energy. Even where L is not of the above form, however, it is still true that if L does not involve t explicitly, $\Sigma \dot{q}_r(\partial L/\partial \dot{q}_r) - L$ is constant with time, so it is convenient to give the name energy to this quantity for the general case

$$\text{Energy} = \Sigma \dot{q}_r \frac{\partial L}{\partial \dot{q}_r} - L$$

and understand by this the energy even for cases where L does involve t explicitly. An analytical equivalent of (54) or (55) is

$$\dot{q}_r = \frac{\partial H}{\partial p_r}; \qquad \dot{p}_r = -\frac{\partial H}{\partial p_r}, \tag{57}$$

where p_r is defined as

$$p_r \equiv \frac{\partial L}{\partial \dot{q}_r} \tag{58}$$

and H is defined as

$$H \equiv \Sigma p_r \dot{q}_r - L, \tag{59}$$

where, however, the $\dot{q}$'s in H are expressed in terms of the q's and p's through equations (58), so that H is a function of the p's and q's and of t.

It is an analytical consequence of (57) that

$$\frac{dH}{dt} = -\left(\frac{\partial L}{\partial t}\right) p\text{'s and } q\text{'s constant.} \tag{60}$$

Again, if $L = T - V$ and T is a homogeneous quadratic function of the velocities and V a function of coördinates and time, $H = T + V$, and is constant with time if L does not involve t explicitly.

In general, if

$$L = T' - V,$$

where T' is merely a function of velocities, coördinates and time, but not a homogeneous quadratic function, the energy $\Sigma p_r \dot{q}_r - L$ will be something other than $T' + V$, and it will be this something which will be constant with time or equal to $-(\partial L/\partial t)$ according as L does or does not involve t explicitly.

Thus, suppose for an assemblage of electrons

$$L = \Sigma_i - m_{0i}c^2\sqrt{1 - \beta_i^2} - e\varphi_i + \frac{e}{c}(U_{xi}u_{xi} + U_{yi}u_{yi} + U_{zi}u_{zi}), \tag{61}$$

where

$$c^2\beta^2 = u_x^2 + u_y^2 + u_z^2$$

and where, in considering the values of U_i and φ_i, we consider only the contributions from charges other than the electron denoted by the subscript i. The quantity L satisfies the requirements we have imposed on L, the requirements of being a function of the q's, the $\dot{q}$'s and t.[10] Equation (58) then leads to

$$\mathbf{p}_i = \frac{m_{0i}\mathbf{u}_i}{\sqrt{1-\beta_i^2}} + \frac{e}{c}\mathbf{U}_i. \tag{62}$$

On making use of this in (59) we find

$$H \equiv \Sigma_r p_r \dot{q}_r - L = \Sigma_i \left\{ \frac{m_{0i}c^2}{\sqrt{1-\beta_i^2}} + e\varphi_i \right\}, \tag{63}$$

so that if the φ_i and $\mathbf{U}_i$ are independent of t explicitly, so that L is independent of t explicitly

$$\Sigma_i \left\{ \frac{m_{0i}c^2}{\sqrt{1-\beta_i^2}} + e\varphi_i \right\} = \text{constant}.$$

Whether this quantity is constant with time or not, it is, as we have remarked, what we call the energy, since it is the quantity which is constant when L is independent of t explicitly.

In the case of a single electron and an external field specified by φ_i and $\mathbf{U}_i$, as functions of position and time, φ_i involves only the coördinates and time, so that it is appropriate to call $e\varphi_i$ the potential energy. It is then appropriate to call $m_{0i}c^2/\sqrt{1-\beta^2}_i$ the kinetic energy T. Or since it is customary to regard T as zero when β is zero, we take

$$T \equiv m_i c^2 \left(\frac{1}{\sqrt{1-\beta^2}_i} - 1 \right)$$

[10] Strictly speaking, the conclusion is not true for $\mathbf{U}$ and φ involve the values of the velocities at retarded times, and when these are expressed in terms of instantaneous values all the higher time derivatives come in. This point does not seem to be taken into account as a rule. It usually causes no harm since the case concerned is usually that of a single electron and $\mathbf{U}$ and φ are then expressed as solutions of the wave equation and regarded as having origin in some other system which is unaffected by the electron. Expressed in this way, they occur simply as functions of the coördinates of the electron i and of the time.

the addition of the constant term does not, of course, affect the condition

$$\frac{d}{dt}(T + V) = -\frac{\partial L}{\partial t},$$

The quantity we have called T' is, in the present case,

$$T' = -m_{0i}c^2\sqrt{1 - \beta_i^2}.$$

Whether φ_i and $\mathbf{U}_i$ are, or are not, independent of t explicitly, it results on applying (54) or (55) to L, that

$$-\frac{1}{c}\frac{\partial \mathbf{U}_i}{\partial t} - \text{grad } \varphi_i + \frac{1}{c}[\mathbf{u}_i \text{ curl } \mathbf{U}_i] = \frac{d}{dt}\left(\frac{m_{0i}\mathbf{u}_i}{\sqrt{1 - \beta_i^2}}\right), \quad (64)$$

so that from (39) and (40)

$$\left(\mathbf{E}_{0i} + \frac{[\mathbf{u}_i\mathbf{H}_{0i}]}{c}\right)e = m_{0i}\frac{d}{dt}\left\{\frac{u_i}{\sqrt{1 - \beta_i^2}}\right\}. \quad (65)$$

Thus we may regard (61) as the appropriate expression for L in order to give rise to the equations of motion (65) by the usual dynamical procedure. In (64) we should regard $\mathbf{U}_i$ and φ_i as defined in terms of the charges of the system by (41) and (42). The quantities $\mathbf{E}_{0i}$ and $\mathbf{H}_{0i}$ need never be used at all except in the light of a shorthand notation. If they are introduced as a matter of convenience, they must be regarded in the light of being defined by (39) and (40); and, in the light of this definition, their obedience to (1)–(4) is guaranteed. We have to choose our Lagrangian function L in any case; and, having chosen it in terms of φ and $\mathbf{U}$, the complete story is told in a way which is definite. It may be wrong, but it is definite, and $\mathbf{E}_{0i}$ and $\mathbf{H}_{0i}$ need never make their appearance at all except in the character of a scaffolding. It is of interest to note that the quantity which we usually call the momentum of an electron i, viz.: $m_{0i}\mathbf{u}_i/\sqrt{1 - \beta_i^2}$ is not the same thing as the generalized momentum of the system *associated* with the electron i, the latter quantity is given by (62).

It is perhaps worth while to emphasize that the application of (54) or (55) to (61) to obtain (64) or (65) is not to be

regarded as a proof of (64) or (65), since the choice of (61) rests on its being the suitable function for this purpose. All that is shown is that (64) or (65) is the analytical equivalent of applying (54) or (55) to (61). Indeed, it is probable that most so-called proofs in physics should be regarded more in the light of showing the analytical equivalence of different statements of a law.

We know that, with suitable definitions of the quantities concerned, (65) is invariant under the restricted relativity transformation. We should expect that this would be the case if Ldt were invariant in form under the Lorentzian transformation. It is easy to see that this invariance holds. For, writing $k_i \equiv (1 - \beta_i^2)^{-1/2}$, dt/k_i is known to be an invariant. Also, $k_{xi}u_{xi}$, $k_{yi}u_{yi}$, $k_{zi}u_{zi}$, $kc\sqrt{-1}$ is a 4-vector. It is the velocity 4-vector. Also

$$U_{xi},\ U_{yi},\ U_{zi},\ \varphi\sqrt{-1} \text{ is a 4-vector.}$$

Thus $m_{0i}c^2\sqrt{1 - \beta_i^2}dt = moc^2dt/k_i$ and is invariant. Also

$$U_{xi}u_{xi} + U_{yi}u_{yi} + U_{zi}u_{zi} - c\varphi_i = (U_{xi}k_iu_{xi} + U_{yi}k_iu_{yi} + U_{zi}k_iu_{zi} - ck_i\varphi_i)\frac{dt}{k_i}$$

and is therefore invariant. Hence, Ldt is invariant.

It is, of course, possible to deduce (65) from the Hamiltonian equations (57). For this purpose we need the Hamiltonian function for an electron. This is to be obtained by substituting for the $\dot{q}$'s in (59) their values in terms of the q's and p's from (62). In this way we readily obtain for a single electron

$$H = c\left[\left(p_x - \frac{e}{c}U_x\right)^2 + \left(p_y - \frac{e}{c}U_y\right)^2 + \left(p_z - \frac{e}{c}U_z\right)^2 + m_0^2c^2\right]^{1/2} + e\varphi.$$

The Magnetic Susceptibility of Aluminium. C. CHÉNEVEAU. (*Comptes Rendus*, April 23, 1928.) Two specimens were tried in the magnetic balance and found to have as their susceptibilities per gram 0.585 and 0.579 $\times 10^{-6}$ respectively. They were prepared by Hoopes' process and had the following composition by per cent., Al, 99.87; Fe, .06; Si, .03; Cu, .04. In shaping the specimens traces of iron were left on their surfaces. The effects of these had to be eliminated. Owen in his determination of the susceptibility of aluminium used metal containing .15 per cent. iron and got a value of .62 $\times 10^{-6}$ and Honda's aluminium had an iron content of .24 per cent. and gave a value of .65 $\times 10^{-6}$. The author measured the susceptibility of aluminium wire containing .5 per cent. iron and got a mean value of .59 $\times 10^{-6}$ that scarcely differed from his previous result when greater precautions were taken. Had the contained iron alone been present and acted magnetically as normal metallic iron its effects would have exceeded the capacity of the magnetic balance. If the iron present were in the condition of ions it by itself should make the susceptibility to be more than three times as great as the value found for the aluminium specimen. A comparison of the values obtained by others with the iron content of their aluminium leads to the conclusion that "small quantities of iron alloyed with aluminium in general change very little the magnetic properties of the latter. The iron seems to act quite differently from its behavior in the metallic or ionic states, its magnetic qualities being considerably reduced as is the case in certain other alloys." G. F. S.

R. A. MILLIKAN and his coadjutors have continued to investigate the extraction of electrons from metals in high vacuum by the action of electric fields. (*Phys. Rev.*, May, 1928.) It takes a field of more than 2,000,000 volts per cm. to cause the smallest current they could accurately measure to flow from platinum whereas less than half of that field strength sufficed to pull the same current from a tungsten point.

In the experiments just mentioned the metal was the cathode. When it was made the anode no current at all was obtained when 100,000 volts was applied from a direct current generator. The field corresponding to this amounted to 35,000,000 volts per cm. Here is a sharp contrast between the behaviors of the two kinds of electricity. G. F. S.

THE PROBLEM OF ARSENICAL SPRAY RESIDUE. *

BY

HOWARD W. AMBRUSTER.

THE seemingly insurmountable obstacle now confronting those who, for commercial or scientific reasons, desire to continue the extensive use of arsenic and other stomach poisons for agricultural insect control, is summed up in a recent address by Dr. A. J. Carlson of the Hull Physiological Laboratory of the University of Chicago.[1] Dr. Carlson discusses the many phases of modern man-made environment from the viewpoint of scientific and medical research and concludes with this rather distressing query, "Are the ablest, the strongest, the wisest men merely grave diggers in disguise?"

Of the so-called "spray-residue" problem he says: "Lead and arsenic are taken into our system with the apple and the pear. We may not consume enough lead and arsenic in our fruit to produce acute poisoning and tissue injury, but who is there to say that this slow assimilation of metallic poisons brought about by modern industry is without danger and ultimate injury? The only factor of safety that I can see in this situation is the phenomenon of tolerance, that is, the capacity of the living organism, if it is not seriously wrecked by the poisons, to so adjust the internal processes as to render the poisons less and less injurious."

Again, in discussing tests on another problem involving foodstuffs Dr. Carlson stated: "It would seem a safer principle for governments and society to insist that the burden of proof of harmlessness falls on the manufacturer or the introducer of new food substitutes rather than on society, and the tests of the harmfulness or harmlessness should involve all the physiological processes of man."

For many years there has been abundant evidence available for those who have studied the subject that the increasing use of arsenic and other stomach poisons for agricultural insect

* Address at 75th Meeting of American Chemical Society, St. Louis, Mo., April, 1928.

[1] Address at Race Betterment Conference, Battle Creek, Mich, Jan. 1928, pub. in *Science*, Vol. LXVII, no. 1736.

control would ultimately result in a conflict between two scientific groups, the entomologists and the health authorities. And it has been equally obvious that as far as the general public was concerned, the entomologists would have no convincing arguments to put forth in meeting objections from health officials to the use of poisons on foodstuffs.

As the concrete problem has developed the sound of the word "arsenic" to the lay mind is the greatest menace in the whole situation. But it is the lead in lead arsenate which carries the greatest actual danger to the public health. Yet paradoxically the lay mind is so accustomed to the many uses of lead in non-dangerous phases of human environment that the name of this poison does not cause the immediate reaction of precaution and fear attached to arsenic.

Lead arsenate is the standard arsenical insecticide of most universal application for a wider range of insect control purposes than any other single type of insecticide. Paris green, in the past, was the most used as it was the first arsenical compound to gain recognition as an insecticide but its use now, though still considerable, is relatively unimportant as it has been replaced largely by lead or calcium arsenate. Calcium arsenate is affected indirectly by the residue situation which will prevent the extension of its use in some directions where it has been encroaching on Paris green. But the largest actual and potential use of calcium arsenate is for the control of the cotton insects and in this field the residue problem is not a factor.

As long ago as 1912 scientific investigation of the "possibility of danger resulting from residues of arsenate of lead remaining on fruit or foliage after spraying with that material" [2] was undertaken at the New Hampshire Agricultural Experiment Station under the direction of that able and farseeing entomologist, Dr. W. C. O'Kane.

The conclusions from this investigation covered the possible effect of spray residues on healthy human adults and also on live stock. But they were not conclusive nor were they so regarded by those who conducted them. If this investigation had been properly followed up along the lines which it indicated, there would be no spray residue problem today as it would have been solved long before.

[2] O'Kane, Hadley and Osgood, Bulletin 183, New Hamp. Agri. Exper. St.

Included in the final report was a statement by the same authority already quoted, Dr. A. J. Carlson, as follows: "Speaking as a physiologist interested in public health I should say the question is not how much of the poison may be injested without producing acute or obvious chronic symptoms, but how completely can man be safeguarded against even traces of the poison. There is no question in my mind that even in less than the so-called toxic doses lead and arsenic have deleterious effects on cell protoplasm, effects that are expressed in lowered resistance to disease, lessened efficiency, and shortening of life."

Unfortunately no agitation of the residue subject developed until several years later when it came to the front again as an issue through the condemnation of several fruit shipments from the Pacific coast by New England health officials on account of arsenical residues found thereon. These cases did not excite much public or official comment, however, nor did the occasional and unconfirmed reports of poisoning from sprayed fruit and vegetables which have appeared from time to time in the public press. In 1926 however the problem became suddenly acute on account of the condemnation of numerous shipments of American apples by English authorities. It has remained a live issue ever since. The great element of uncertainty about it, and the phase of it which absolutely prevents its prompt solution, is the fact that there is no legal tolerance or standard of limitation for the amounts of arsenic and such poisons which are permissible legally, or safe from a health standpoint, in foodstuffs.

For a considerable period every effort was made by those involved to keep this problem from discussion in the public, or trade, press on account of the fear that the public would become unduly alarmed to learn that such a problem even existed. However, in the last year so much official and unofficial mention of the subject has been made that many now question whether it can longer be considered a subject regarding which the general public can be kept in ignorance. In any event some phases of it are now getting very wide publicity in official and trade publications and the demand for a final fixing of an official or legal tolerance must ultimately force it to a solution no matter what interests are hurt by such an outcome.

One of the unaccountable phases of the present situation is the fact that many of those concerned refer to what is known as the British "tolerance" on arsenic in foodstuffs (1/100 of a grain per pound of foodstuffs) as though it were a legal requirement in England, whereas no such official tolerance has ever been adopted by the English government. Similarly, references are frequently made at public meetings and elsewhere of the official standards of "tolerance" in this country as ranging from two and one-half to four times the so-called British standard. Yet as a matter of fact there is no official or legal standard in this country either. The question is simply up in the air and apparently no one knows what the safe tolerance may be or what the legal tolerance should be.

However, as an illustration of the seriousness of the legal aspects of the problem and as showing how the shipper of foodstuffs are affected, may be cited the following from the charge of the judge in a case brought in the Federal courts involving interstate shipments of fruit. The judge said: "The statute forbids adulteration of a food product, and the articles shall be deemed to be adulterated in case of foods if they contain any added poisonous or other added deleterious ingredient which may render such article injurious to health. . . . It is not required that the article of food containing added poisonous or added deleterious ingredients must affect the public health, The word 'may' is used here in its ordinary and usual significance, there being nothing to show the intention of Congress to affix to it any other meaning." [3]

It should be stated here that although the agitation about the residue is mainly centered on apples as the most important food crop thus affected, it extends in greater or less degree through practically all other fruit crops and many of the truck crops. Until the question of tolerance is finally settled, the spray residue problem will hang over every item of foodstuffs which during the period of growth have by any possibility an opportunity to retain any stomach poison insecticide.

That there is a menace to health in the absorption of arsenic or other stomach poisons, no sane person will deny. It is therefore the part of wisdom to seek out the facts in the

[3] U. S. D. of A. notices of Judgment under the Food and Drugs Act, 15350 issued Feb. 1928.

spray residue problem rather than to deny or belittle them. To many, the word poison is synonymous with arsenic and rightly so as practically the only utility of this element, except its use in glass making, is due to its poisonous quality. Yet we may quote two apparently contradictory statements regarding arsenic in a recently published work on poisons as follows: "Arsenic is by far the most important of metallic poisons whether we consider the deadliness of its effects or the frequency of its use. . . . The peasants in parts of Styria and Hungary are said to eat arsenic, taking from two to five grains daily . . . in order that they may gain in strength and be able to endure fatigue." [4]

In connection with the present agitation about arsenical spray residues it might well be recalled that arsenic has always been feared in foodstuffs since the historical days when the king's taster had the unpleasant job of sampling the soup before it was partaken of by his majesty for fear an enemy had made his way into the royal kitchen.

More recent examples which may be cited as indicative of the fear which exists on the subject of arsenic in articles for human consumption are found in a recent article by Dr. Roe E. Remington, of the North Dakota Agricultural College, as follows: "As long ago as 1913 the North Dakota Food Commissioner set up one part per million as the maximum permitted in baking powder. . . . Arsenic in foods through chemical treatment has been familiar since the time of the Manchester beer cases through the use of impure acid in making glucose. Although the maximum amount of arsenic found in any of the samples of beer analyzed was only four parts per million, hundreds of persons were made ill and numbers died. . . . Samples of American smoking and plug tobacco have been examined for arsenic and found to contain from six to thirty parts per million, or from 9.95 to 9.27 grains of arsenic trioxide per pound. Amounts of arsenic reported are much in excess of the maximum permitted by the state and federal authorities in foods, and of the amounts normally present in plants and animals." [5]

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[4] Trumper, Memoranda of Toxicology, 1925.

[5] "A hitherto unsuspected source of arsenic in human environment," *Jour. of the Am. Ch. Soc.*, Vol. 49, No. 6, June, 1927.

It might be justly said that at the present time a great deal of earnest work is being done in connection with the residue question, new insecticides and new methods of control and reduction of the residue on fruit by washing and other methods. This work is all unintelligent however in that no one knows exactly what is required, nor can any one know this until the question of tolerance is settled.

In default of the final settling of the question of tolerance, the question will be solved with the development of a non-poisonous insecticide which will give relatively as good control for the insects considered as is now secured with the use of lead arsenate or other stomach poisons.

There is definite evidence of progress along these lines in the compounding of oil sprays and, in certain limited fields, some of the non-poisonous botanicals have evident value as contact insecticides. It is certain that any orchardist or truck grower when convinced that he can secure approximately as good control with an insecticide which eliminates the hazard of the residue problem as it now exists, will abandon the stomach poisons as a matter of common sense no matter what his dependence on them in the past. If after such a solution should come about the inertia which now prevents the question of tolerance from being settled is overcome and the result then permits the safe use of some stomach poisons within definite limitations, it will be too late then ever to restore such types of insecticides to their present status of supremacy.

On another aspect, the problem may be solved for certain types of insect control by what Dr. L. O. Howard so aptly named "the biological method of fighting insects." [6]

For several of the most important entomological problems where lead arsenate is now proscribed or threatened, the introduction of other parasitic and predatory insects is being tried out on a large systematic scale with a view of eradicating or reducing certain pests. However it takes long years of research and field work to accomplish definite results along these lines and final success is always menaced by the hazard that the new pest may be worse than the old.

As a practical workaday problem the spray residue problem

[6] "The Practical Use of the Insect Enemies of Injurious Insects," Yearbook, U. S. D. of A., 1916.

might be said to concern only the fruit and truck growers. Unfortunately the repercussions of this problem are found in many other groups, industrial, commercial, professional and official.

The entomologist is vitally interested because the greatest progress made in insect control since economic entomology attained the status of a science, has been largely based on the use of arsenical compounds. And the other stomach poisons are, of course, threatened by the same ban which hangs over arsenic. But the entomologist, not being a medical man, does not know which one to pick.

The entomologists are therefore striving to solve a problem of selecting materials for insect control work when they are completely in the dark as to what materials they will be permitted to use in the future.

The insecticide manufacturers are also vitally interested in this problem, both those making arsenical compounds or other stomach poison insecticides and those making only contact or repellant insecticides. The fog of uncertainty which hangs over these industries on account of the unknown factor of spray tolerance has caused stagnation of effort in extending existing industries or developing new ones.

The shippers of fruit and other foodstuffs affected are sorely harassed and disturbed on account of the ever present danger of official seizure of the commodities in which they deal and the still greater danger that the public may take alarm at a possible danger, and, through hysteria excited by the sound of the word arsenic, may suddenly turn against types of foodstuffs produced in various agricultural districts.

The group which must necessarily take cognizance of this problem, and whose final recognition of it brought about the present crisis, includes the pure food law and health law officials, federal, state and municipal. They are faced with a possible ambiguity of the laws on the one hand and lack of medical knowledge on the other. Also they fear that they may so handicap the entomologist that it will be impossible to protect the very crops which they desire to be kept free from poisonous contamination.

Obviously the spray residue problem is a complex one, affecting as it does so many important groups. In its finality

however it must be met by medical science along the lines so ably summed up by Dr. Carlson. Those of us who are mainly interested in arsenic and other stomach poisons must take into account the fact that it is primarily a problem which must be settled first in terms of toxicology and physiology and all other phases of it worked out from a basis of standards set by those sciences. Until it is so settled all the groups affected will remain in a state of uncertainty and chaos. And the danger will continue of a public hysteria which may result in a calamity to some of the agricultural groups involved.

SCHRÖDINGER DYNAMICS.

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THE Schrödinger theory is based on the hypothesis that the fundamental properties of the electron can be derived from the solutions of the wave equation

$$\nabla^2\psi - \frac{1}{u^2}\frac{\partial^2\psi}{\partial t^2} = 0 \qquad (1)$$

with

$$u^2 = \frac{E^2}{2m(E - V)},$$

where V is the potential energy function, the same as was used in the classical quantum theory to describe the energy of the external forces acting on the electron, where m is the mass of the electron and where E is a characteristic constant whose value represents the total amount of energy the atomic system has available for radiation.

When, however, we attempt to analyze the properties of the electron still further so as to find, e.g., the distribution of charge density or the motion of the center of electronic mass—so far we have only found a method to determine the value of the energy available as radiation, i.e., the value of E—we encounter grave difficulties. Various hypotheses have been made, none of which seems to be completely satisfactory.

The most direct method, however, is to assume that the motion of the electron is such that the direction of its motion coincides with the direction of the normal to the wave surfaces ψ = constant. This is one of the important results which the experiment of Davisson and Germer has demonstrated and which, therefore, rests on a sound experimental basis. We are also familiar with a similar hypothesis in the quantum

theory of radiation in which the light quantum is supposed to travel along the normal to the wave front, in the case of a plane wave, found as a solution of the equation

$$\nabla^2\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = 0. \qquad (2)$$

These two wave equations (1) and (2) which specify the motion of the electron and quantum, respectively, have several properties in common. The frequency of the vibrations of the function ψ appearing in equation (2) is given by by the relation

$$\nu = E/h,$$

where E is the amount of radiant energy associated with one quantum and "h" is Planck's constant; in the wave theory of the electron's motion a similar relationship holds. The frequency of the vibrations of ψ in this case is given by the relation,

$$\nu = E/h;$$

here E represents the amount of energy available as radiant energy.

We can, therefore, treat these two distinct equations as special cases of the general wave equation

$$\nabla^2\psi - \frac{1}{u^2}\frac{\partial^2\psi}{\partial t^2} = 0,$$

$$\psi(x\ y\ z\ t) = \overline{\psi}(x\ y\ z)e^{(2\pi i/h)Et},$$

where E has the significance mentioned above, and where $u^2 = c^2$ for the quantum phenomena of optics, and

$$u^2 = \frac{E^2}{2m(E - v)}$$

for electronic phenomena.

Substituting the value of ψ in terms of $\overline{\psi}$ and the time t, we find the spatial equation

$$\nabla^2\overline{\psi} + \frac{4\pi^2E^2}{u^2}\overline{\psi} = 0 \qquad (3)$$

as the general equation from which the properties of the motion of the particle may be investigated.

We shall now proceed to derive the equations of motion of the electron or quantum on the basis of the assumption we have discussed above, namely, that the direction cosines l, m and n of the normal to the surface

$$\bar{\psi}(xyz) = \text{constant},$$

where

$$l = \frac{\partial\bar{\psi}}{\partial x} \Big/ \sqrt{\left(\frac{\partial\bar{\psi}}{\partial x}\right)^2 + \left(\frac{\partial\bar{\psi}}{\partial y}\right)^2 \left(\frac{\partial\bar{\psi}}{\partial z}\right)^2}$$

and where similar expressions hold for m and n, that these direction cosines are equal to the direction cosines α, β and γ of the tangent to the particles trajectory at the same point where

$$\alpha = \frac{dx}{dt} \Big/ \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2 + \left(\frac{dz}{dt}\right)^2}$$

and similar expressions for β and γ.

We shall now limit the discussion to the case where the momenta

$$px = m\frac{dx}{dt}, \quad \text{etc.}$$

can be expressed as a function of position independent of the time, i.e., we shall set

$$px = \frac{\partial W}{\partial x}, \quad \text{etc.}$$

Since it is only problems of mechanics where a velocity potential exists which can be solved completely, this restriction merely limits our attention to those problems which are of interest.

Equating now the components of the direction cosines, we have that

$$\frac{\partial\bar{\psi}}{\partial x} \Big/ \sqrt{\left(\frac{\partial\bar{\psi}}{\partial x}\right)^2 + \left(\frac{\partial\bar{\psi}}{\partial y}\right)^2 + \left(\frac{\partial\bar{\psi}}{\partial z}\right)^2} = \frac{\partial W}{\partial x} \Big/ \sqrt{\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2}$$

together with two other equations for the "y" and "z" components whose solution is that $\overline{\psi}$ is a function of W,

$$\overline{\psi} = f(W).$$

If now we substitute this value for $\overline{\psi}$ in terms of W into the spatial equation

$$\Delta^2\overline{\psi} + \frac{4\pi^2E^2}{u^2}\overline{\psi} = 0$$

we shall have a differential equation for W, from which to determine the motion of the particle.

Making the substitution for $\overline{\psi}$ in terms of W, we have since

$$\frac{\partial\overline{\psi}}{\partial x} = f'\frac{\partial W}{\partial x}, \qquad f' = \frac{\partial f}{\partial W}$$

and

$$\frac{\partial^2\overline{\psi}}{\partial x^2} = f''\left(\frac{\partial W}{\partial x}\right)^2 + f'\frac{\partial^2 W}{\partial x^2},$$

that

$$f'[\nabla^2 W] + f''\left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2\right] + \frac{4\pi^2E^2}{u^2}f = 0$$

or, dividing by f and replacing u^2 by its value for the electron, namely

$$u^2 = E^2/2m(E - V)$$

we have that

$$\left(\frac{f'}{f}\right)[\nabla^2 W] + \left(\frac{f''}{f}\right)\left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2\right] + \frac{8\pi^2 m}{h^2}(E - V) = 0. \quad (4)$$

In order to find the form of the function $f(W)$ we will have to use the principle that the quantum phenomena degenerate into the phenomena of classical mechanics as Planck's constant "h" approaches zero. For example, we have from Planck's radiation theory that the energy density of radiation belonging to wave lengths between λ and

$\lambda + d\lambda$, $L(\lambda)d\lambda$, is given as a function of the temperature T and the wave-length λ by

$$L(\lambda)d\lambda = \frac{8\pi^2 ch}{\lambda^5} \frac{d\lambda}{e^{ch/\lambda RT} - 1},$$

where

c = velocity of light

and

R = gas constant.

If now we take the limit of $L(\lambda)d\lambda$ as h approaches zero, we obtain as the value of $L(\lambda)d\lambda$ $L(\lambda)d\lambda = \frac{8\pi RT}{\lambda^4} d\lambda$, the Rayleigh-Jeans' law which is based on classical mechanics.

The restriction is similar to the one of restricted relativity in that if we allow the value of the constant "c," the velocity of light, which appears in the equations of relativity, to approach infinity, the equations of motion degenerate into the laws of classical mechanics.

We shall now use the above principle to determine the form of the function $f(W)$ so that this condition is satisfied.

Since in the limit when $h = 0$, equation (4) has the form

$$\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2 - 2m(E - V) = 0,$$

then

$$\lim_{h \doteq 0} f'/f = 0$$

and

$$\lim_{h \doteq 0} f''/f = -\frac{4\pi^2}{h^2}.$$

A solution of these two equations is

$$f(W) = e^{(2\pi i/h)W},$$

so that the energy equation (4) takes the form

$$\frac{h}{2\pi i}\nabla^2 W + \left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2 - 2m(E - V)\right] = 0. \quad (5)$$

The above equation represents the energy integral of the equations of motion of an electron which is consistent with the two restrictions (i) that the direction of the normal to the wave surfaces $\bar{\psi}$ = constant is the same as the direction of the tangent to the trajectory of the electron's motions passing through the same point in space and (ii) that the energy integral degenerates as $h = 0$ to the energy integral of classical mechanics.

If we had started from the spatial equation for the light quantum instead of that for the electron we would have, by the same process of analysis, arrived finally at the energy integral

$$\frac{h}{2\pi c}\nabla^2 W + \left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2 - \left(\frac{E}{c}\right)^2\right] = 0. \quad (6)$$

The solution of this equation is subject to no other conditions than those required by the periodicity of the motion.

Since the energy integral, equation (5), corresponds to the motion of an electron which does not radiate any energy beyond the confines of the system, i.e., into space where an observer can detect the same, the motion must be such that the value of the momenta $px = \frac{\partial W}{\partial x}$, etc., must assume for any point on the trajectory the same values after every complete revolution or cycle of the system. For example, in the case of the rotator, which consists of a particle of mass M moving in a fixed circle about a center of constraint, the origin, the value of the momentum $p\theta$, if we use polar coördinates in which the angle θ is used to designate the position of the particle, must assume the same value after every increase or decrease of the angle θ by 2π. This is equivalent to assuming that the momenta, in the case where the motion is cyclic, are independent of the time, explicitly, and can therefore be expressed as the derivates of a velocity potential, or, in other words, as a point function.

We shall now consider the type of motion of the electron and light quantum respectively in a few simple cases which are of particular interest.

THE FREE ELECTRON.

The wave equation for the free electron is

$$\nabla^2\psi - \frac{2m}{E}\frac{\partial^2\psi}{\partial t^2} = 0,$$

so that the energy equation of the electron itself has the form

$$\frac{h}{2\pi i}\nabla^2 W + \left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2 - 2mE\right] = 0.$$

or if the motion is restricted to paths which are parallel to the x-axis in the Cartesian coördinate system we are employing,

$$\frac{h}{2\pi i}\frac{\partial^2 W}{\partial x^2} + \left(\frac{\partial W}{\partial x}\right)^2 = 2mE.$$

If we set $\frac{\partial W}{\partial x} = p$ = momentum of electron along x-axis, then the equation takes the form

$$\frac{h}{2\pi i}\frac{\partial p}{\partial x} + p^2 - 2mE = 0,$$

whose general integral is

$$\frac{1}{\sqrt{2mE}}\log\frac{p - \sqrt{2mE}}{p + \sqrt{2mE}} = \frac{2\pi i}{h}x + c,$$

where c = constant; or

$$\frac{p - \sqrt{2mE}}{p + \sqrt{2mE}} = A\cos\frac{2\pi}{h}\sqrt{2mE}\cdot x;$$

or

$$p = \sqrt{2mE}\left\{\frac{1 \pm A\cos\frac{2\pi}{h}\sqrt{2mE}\cdot x}{1 \mp A\cos\frac{2\pi}{h}\sqrt{2mE}\cdot x}\right\}. \qquad (7)$$

The velocity of the electron p/m in the case is no longer constant, but fluctuates about a mean value, which is the

same as the classical value, namely, $\frac{\bar{p}}{m} = \sqrt{2mE}/m$, mean value of velocity.

The fluctuations are such that when the electron traverses a distance

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{h}{\bar{p}}$$

the value of the momentum is the same at the two end points. Moreover, we see that this distance λ is the same as the wave-length of the de Broglie waves associated with the particle so that we can regard these fluctuations in velocity as due to the reaction of the ψ field on the electron, retarding or accelerating it as the phase angle between the vector field and the direction of motion changes.

If we regard the constant E, as the energy available as radiation, rather than as the total energy of the system, then from the above equation we see that the energy E is the same as the kinetic energy of the particle calculated by the classical mechanics, i.e.,

$$E = \left| \frac{\bar{p}^2}{2m} \right| \quad \text{mean value,}$$

a result which has its experimental verification in the wave-length limit of the continuous X-ray spectrum.

From equation (7) which expresses the relationship existing between the momentum and the coördinate x, we see that we cannot assign any definite value to the momentum and, therefore, to the kinetic energy of the particle, but only a mean value about which these quantities oscillate as the particle describes the trajectory, the value of the oscillation depending on the value of the constant of integration A. The fact that we cannot assign a definite value to the energy of a free electron but only a mean value is in keeping with the spirit of the principle of indetermination which lately has been developed by Heisenberg and others.

The wave mechanics definition of charge density as the product of ψ by its conjugate imaginary leads to the conception of the wave packet which behaved like a point mass

of the usual mechanics. The discovery that this wave packet diffused itself indefinitely with the time caused a revision of this conception and lead to the principle of indetermination formulated by Heisenberg. In this paper we replace the conception of the indetermination of the path of a particle by the indetermination in the particular path the particle may move along. In the quantum theory of diffraction the light particles move along the lines of the Poynting flux but which particular line they choose to traverse is determined wholly, as yet, by probability considerations: in this theory of the free electron the same situation arises and brings the indetermination into the choice of the path rather than on the path itself.

However, as we shall see later, the path of the election itself is uniquely determined for those cases where the energy E is assigned to certain fixed values.

In these cases, however, the momentum and kinetic energy of the free electron may vary within definite limits, given by the constant A, about a mean value, although the value of the energy available as radiation, i.e., E, is definite and is equal to the mean value of the kinetic energy. The difference in energy between these two values, which arises when the particle liberates the energy E due to a collision or a radiation process, is taken up by the adjustment of the electron's field ψ and in its internal rearrangement due to the dependence of its mass density on velocity.

THE LIGHT QUANTUM.

We have for the energy integral of a quantum moving parallel to the direction of the x axis,

$$\frac{h}{2\pi i}\frac{\partial^2 W}{\partial x^2}+\left(\frac{\partial W}{\partial x}\right)^2-\left(\frac{E}{c}\right)^2=0$$

or setting $\dfrac{\partial W}{\partial x}=p=$ momentum in the x direction

$$\frac{h}{2\pi i}\frac{\partial p}{\partial x}+p^2-\left(\frac{E}{c}\right)^2=0,$$

whose solution is

$$\frac{p - E/c}{p + E/c} = A \cos \frac{2\pi}{p}\left(\frac{E}{c}\right) \cdot x.$$

We have, therefore, that the average value of the momentum p is equal to the radiant energy E associated with one quantum divided by the velocity of light, $\bar{p} = E/c$, a mean value.

The distance λ which the quantum must travel from any given point before the momentum p repeats its previous value is given by the equation

$$\lambda = hc/E,$$

the same as the wave-length of the light pulse, since

$$\frac{\lambda}{c} = \frac{1}{\nu} = h/E.$$

For electromagnetic radiation the value of the constant A must be extremely small, otherwise the modified line in the Compton Effect would have a large width, measured in wave-length units, compared to that of the unmodified line.

THE ROTATOR.

Using polar coördinates, we have for the energy integral of the rotator since here the potential energy V is zero

$$\frac{h}{2\pi i}\left[\frac{\partial^2 W}{\partial r^2} + \frac{2}{r}\frac{\partial W}{\partial r} + \frac{1}{r^2}\frac{\partial^2 W}{\partial \theta^2} + \frac{1}{r^2}\cot\theta\frac{\partial W}{\partial \theta} + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 W}{\partial \varphi^2}\right]$$
$$+\left[\left(\frac{\partial W}{\partial r}\right)^2 + \frac{1}{r^2}\left(\frac{\partial W}{\partial \theta}\right)^2 + \frac{1}{r^2\sin^2\theta}\left(\frac{\partial W}{\partial \varphi}\right)^2 - 2mE\right] = 0.$$

Since, however, in the rotator, the particle of mass m is constrained to lie on a sphere of constant radius r measured from the origin, we have for the energy equation, limiting the discussion to the case where the particle moves only in the plane φ = constant,

$$\frac{h}{2\pi i}\left(\frac{\partial^2 W}{\partial \theta^2}\right)^2 + \left(\frac{\partial W}{\partial \theta}\right)^2 - 2mr^2E = 0,$$

whose solution is

$$\frac{\dfrac{\partial W}{\partial \theta} - \sqrt{2mE}\cdot r}{\dfrac{\partial W}{\partial \theta} + \sqrt{2mE}\cdot r} = A \cos\left(\frac{2\pi}{h}\sqrt{2mE}\cdot r\theta\right)$$

or setting

$$\frac{1}{r}\frac{\partial W}{\partial \theta} = p = \text{momentum of the particle}$$

$$\frac{p - \sqrt{2mE}}{p + \sqrt{2mE}} = A \cos\left(\frac{2\pi}{h}\sqrt{2mE}\cdot r\theta\right).$$

Here again the average value of the momentum is given by

$$\bar{p} = \sqrt{2mE}, \quad \text{a mean value,}$$

and the wave length λ of the oscillation by

$$\lambda = h/\sqrt{2mE} = h/\bar{p},$$

the same type of expression as for the free electron. In this case, however, we can determine the value of the constant E from the condition that the motion must be periodic since there is no radiation of energy outside the system which an observer might detect. We have, therefore, that when the angle θ increases by an amount equal to 2π, the momentum has the same value as initially. Thus

$$\frac{4\pi^2}{h}\sqrt{2mE}\cdot r = 2\pi n, \quad n = \text{integer}$$

or

$$E = \frac{n^2h^2}{8\pi^2mr^2}.$$

The periodicity condition leads to the same value for the energy available as radiation as that given by the wave equation, an amount of energy equal to the average value of the kinetic energy of the particle.

HYDROGEN ATOM.

The solution of the hydrogen atom is of particular importance because it leads to interesting results concerning

the orbit of the electron and the wave-length of the ψ waves associated with its motion.

The hydrogen atom is the first case which we have treated where the potential energy V plays a role,

$$V = -\frac{e^2}{r}.$$

We shall attempt to find a solution of the energy equation expressed in polar coördinates by assuming that the function W can be expressed as the sum of these separate functions, each a function of one variable only

$$W = R(r) + \Theta(\theta) + \Phi(\varphi),$$

then the energy integral takes the form

$$\frac{h}{2\pi i}\left[\frac{\partial^2 R}{\partial r^2} + \frac{2}{r^2}\frac{\partial R}{\partial r} + \frac{1}{r^2}\frac{\partial^2 \Theta}{\partial \theta^2} + \frac{1}{r^2 \sin\theta}\frac{\partial^2 \Phi}{\partial \varphi^2} + \frac{\cot\theta}{r^2}\frac{\partial \Theta}{\partial \theta}\right]$$
$$+\left[\left(\frac{\partial R}{\partial r}\right)^2 + \frac{1}{r^2}\left(\frac{\partial \Theta}{\partial \theta}\right)^2 + \frac{1}{r^2 \sin^2\theta}\left(\frac{\partial \Phi}{\partial \varphi}\right)^2 - 2m(E - V)\right] = 0,$$

an equation which we can write in the form

$$\frac{hr^2}{2\pi i}\left[\frac{\partial^2 R}{\partial r^2} + \frac{2}{r}\frac{\partial R}{\partial r}\right] + r^2\left(\frac{\partial R}{\partial r}\right)^2 - 2mr^2\left(E + \frac{e^2}{r^2}\right)$$
$$= -\frac{h}{2\pi i}\left[\frac{\partial^2 \Theta}{\partial \theta^2} + \cot\theta\frac{\partial \Theta}{\partial \theta}\right] - \left(\frac{\partial \Theta}{\partial \theta}\right)^2$$
$$-\frac{1}{\sin^2\theta}\left[\frac{h}{2\pi i}\frac{\partial^2 \Phi}{\partial \varphi^2} + \left(\frac{\partial \Phi}{\partial \varphi}\right)^2\right].$$

Since each side of this equation is a function of a different variable, we can equate each to a constant β, then we have that

$$\frac{h}{2\pi i}\left[\frac{\partial^2 \Theta}{\partial \theta^2} + \cot\theta\frac{\partial \Theta}{\partial \theta}\right] + \left(\frac{\partial \Theta}{\partial \theta}\right)^2 = \beta - \frac{1}{\sin\theta}\left[\frac{h}{2\pi i}\frac{\partial^2 \Phi}{\partial \varphi^2} + \left(\frac{\partial \Phi}{\partial \varphi}\right)^2\right],$$

an equation which we can write in the form of two separate equations,

$$\frac{h}{2\pi i}\frac{\partial^2 \Phi}{\partial \varphi^2} + \left(\frac{\partial \Phi}{\partial \varphi}\right)^2 = \gamma \qquad (8)$$

and

$$\frac{h}{2\pi i}\left[\frac{\partial^2\Theta}{\partial\theta^2}+\cot\theta\frac{\partial\Theta}{\partial\theta}\right]+\left(\frac{\partial\Theta}{\partial\theta}\right)^2=\beta-\frac{\gamma}{\sin^2\theta}, \qquad (9)$$

where γ is an undetermined constant.

The solution of (8) is

$$\frac{\frac{\partial\Phi}{\partial\varphi}-\sqrt{\gamma}}{\frac{\partial\Phi}{\partial\varphi}+\sqrt{\gamma}}=Ae^{(2\pi i/h)\sqrt{\gamma}\varphi}.$$

From the periodicity condition, the momentum $\partial\Phi/\partial\varphi$ must repeat its values when φ increases by 2π, and we have that

$$\frac{2\pi}{h}\sqrt{\gamma}=n, \quad \text{where } n=\text{an integer}. \qquad (10)$$

We shall omit the discussion of this equation for the present and wait until we have solved the problem completely when we shall be in a better position to understand its significance.

The solution of the equation

$$\frac{h}{2\pi i}\left[\frac{\partial^2\Theta}{\partial\theta^2}+\cot\theta\frac{\partial\Theta}{\partial\theta}\right]+\left(\frac{\partial\Theta}{\partial\theta}\right)^2+\frac{\gamma}{\sin^2\theta}=\beta$$

can be simplified if we set

$$\sin\theta\frac{\partial\Theta}{\partial\theta}=\frac{\partial\mu}{\partial\theta};$$

then we have that μ satisfies the equation

$$\frac{h}{2\pi i}\left[\sin\theta\frac{\partial^2\mu}{\partial\theta^2}\right]+\mu^2+\gamma-\beta\sin^2\theta=0.$$

A particular solution of this equation which corresponds to the motion of the electron in a circular orbit is

$$\mu=a\cos\theta$$

where a and β satisfy the equations

$$a^2 = -\gamma$$

and

$$\beta = -\left(a^2 + \frac{ah}{2\pi i}\right) = \left(\gamma \pm \sqrt{\gamma}\frac{h}{2\pi}\right).$$

Thus we have that

$$\frac{\partial\Theta}{\partial\theta} = i\sqrt{\gamma}\cot\theta = -\frac{nh}{2\pi i}\cot\theta$$

and

$$\beta = \frac{h^2}{4\pi^2}(n^2 \pm n).$$

Since the momentum $\frac{1}{r}\frac{\partial\Theta}{\partial\theta}$ cannot be imaginary, the trajectory of the electron must lie in the plane

$$\theta = \pi/2.$$

The solution of the equation, Riccati's equation,

$$\frac{h}{2\pi i}\frac{\partial P}{\partial r} + \frac{h}{\pi i}\frac{P}{r} + P^2 = \frac{-\beta}{r^2} + 2m\left(E + \frac{e^2}{r}\right), \qquad P = \frac{\partial R}{\partial r}$$

can be simplified if we set

$$P = \frac{h}{2\pi i}\frac{u'}{u}, \qquad u' = \frac{\partial u}{\partial r},$$

for then the equation takes the familiar form

$$\frac{d^2u}{dr^2} + \frac{2}{r}\frac{du}{dr} - \left\{\frac{\beta''}{r^2} - K\left(E + \frac{e^2}{r}\right)\right\} = 0,$$

where

$$K = \frac{8\pi^2 m}{h^2} \quad \text{and} \quad \beta'' = -\frac{4\pi^2\beta}{h^2}.$$

If we set

$$u = e^{\lambda r} \cdot y,$$

then we obtain the equation

$$\frac{d^2y}{dr^2}+\left(2\lambda+\frac{2}{r}\right)\frac{dy}{dr}+\left(KE+\lambda^2+\frac{2\lambda-Ke^2}{r}-\frac{\beta''}{r^2}\right)y=0,$$

from which we can eliminate the constant term in the factor multiplying y by setting

$$\lambda^2+KE=0,$$

$$\lambda=\pm\frac{2\pi i}{h}\sqrt{2mE}.$$

In order to eliminate the term in $1/r$ from the coefficient of y, we set

$$y=r^\sigma\cdot v,$$

obtaining an equation in v of the form

$$\frac{d^2v}{dr^2}+\left[2\lambda+\frac{2(\sigma+1)}{r}\right]\frac{dv}{dr}-\left[\frac{Ke^2-2\lambda-2\sigma\lambda}{r}-\frac{\beta''+\sigma(\sigma+1)}{r^2}\right]v=0.$$

Choosing σ so that

$$\sigma=\frac{Ke^2}{2\lambda}-1,$$

we finally obtain the equation

$$\frac{d^2v}{dr^2}+\left[2\lambda+\frac{2(\sigma+1)}{r}\right]\frac{dv}{dr}+\left[\frac{\beta''+\sigma(\sigma+1)}{r^2}\right]v=0.$$

whose solution can be represented by a series in l/r, a series, however, since it must be finite for all values of r, excluding the origin, must either terminate or be convergent in this interval. This condition is equivalent to assuming that the momentum in the radial direction $\partial R/\partial r$ must always be finite.

A solution of the equation, which corresponds to the case of circular orbits, is v = constant, so that $\beta''=-\sigma(\sigma+1)$; but

$$\beta''=-n(n\pm1)$$

so that

$$\begin{aligned}\sigma &= n \text{ or } -(n+1) \quad \text{using the } + \text{ sign,}\\ &= -n \text{ or } (n-1) \quad \text{using the } - \text{ sign.}\end{aligned}$$

Since

$$\lambda = \frac{\pm 2\pi i}{h}\sqrt{2mE}$$

and

$$\sigma = \frac{Ke^2}{2\lambda} - 1 = \frac{2\pi me^2}{p\sqrt{-2mE}} - 1,$$

we see that the condition σ = an integer cannot be satisfied unless E is negative. Setting $-E = \epsilon$ we find for the type of periodic motion we have been investigating that only certain values for the energy available as radiation are allowable, namely those for which the relation

$$\epsilon = \frac{2\pi^2 me^4}{h^2(n)^2}, \quad \text{where } n = \text{integer}, \tag{11}$$

is satisfied, a condition which is the same as that demanded by the wave theory.

The value of the momentum $\partial R/\partial r$ of the electron along the radius vector, is given by

$$\frac{\partial R}{\partial r} = \frac{h}{2\pi i}\frac{\partial}{\partial r}\log\,(e^{\lambda r}\cdot r^{\sigma}) = \frac{h}{2\pi i}\left[\lambda + \frac{\sigma}{r}\right],$$

but since the momentum cannot be imaginary, the momentum must be zero, and the electron describes a circular orbit whose radius r is given by

$$r = -\frac{\sigma}{\lambda}$$

$$= \frac{n(n+1)h^2}{4\pi^2 me^2}. \tag{12}$$

It is interesting to compare the value of the radius of the circular orbits of the wave theory, given by the above expression, with those of the Bohr theory for which the radius of the orbit is given by

$$r = \frac{n^2h^2}{4\pi^2 me^2}$$

for the same value of the energy E.

The momentum $p = \frac{1}{r}\frac{\partial \Phi}{\partial \varphi}$ of the electron in its orbit fluctuates about the mean value

$$\bar{p} = \left|\frac{1}{r}\frac{\partial \Phi}{\partial \varphi}\right| = \frac{nh}{2\pi r} = \frac{2\pi m e^2}{(n+1)h} \text{ mean value}$$

and the angular momentum varies about the mean value $nh/2\pi$, the same as in the Bohr theory.

The distance which the electron moves before the momentum repeats its value, i.e., the wave-length of the oscillation is given by

$$\lambda = \frac{\sqrt{\gamma}}{hr} = \frac{2\pi m e^2}{(n+1)h^2} = \frac{\bar{p}}{h}$$

or the wave-length of the oscillation is equal to the average momentum in the orbit divided by Planck's constant, a value analogous to that of the free electron.

A Glimpse at the Electrical Changes that Take Place in a Billionth of a Second. W. ROGOWSKI. (*Naturwissenschaften*, March 9, 1928.) For years the author has been investigating the course of rapid electrical processes for the purpose of making them visible and inscribing them on the photographic plate. One such process would be the flow of current into a line upon the closing of a switch. On account of its inertia the moving part of a galvanometer cannot instantly follow the growth of current in the line. A Braun tube, however, has the great advantage of possessing as its pointer a practically massless beam of electrons. In a tube evacuated to a pressure of .001 mm. a potential difference of 30,000 volts between the electrodes causes electrons to travel from the cathode toward the anode which is pierced with a hole. Many impinge on the anode but some pass through the hole and fall on a fluorescent screen some distance away, where they make a bright spot. If the electron beam be subjected to a permanent electrical force the spot will be deflected and if the force vary the spot will change its position accordingly. If two forces at right angles to each other and to the path of the beam act on the electrons the position of the spot will be due to both forces and if both vary in intensity the spot will describe some path. Moreover if one force vary in a known manner the method of variation of the other can be deduced from the form of the path of the light spot. At first the curve of the spot was photographed from the outside of the tube. Thus Zenneck succeeded in tracing processes one-thousandth of a sec. in duration. The photographic plate was next put inside the tube so that the electrons fell directly upon it. With this improvement changes are registered that take place in .00001 to .000001 sec. A further advance was made by directing the electrons so that all passed through the hole in the anode instead of many wasting themselves on the metal of the electrode. This made it possible to get a photographic record of what occurs in a billionth of a second. The substitution of a hot cathode has the advantage of assuring a plentiful supply of electrons but this is at the expense of a great deal of scattering. Curves obtained for almost instantaneous changes such as the discharge of a capacity through a circuit have abscissas in which 4 or 5 mm. equals .0000001 sec. G. F. S.

A NEW FIRST ORDER THEODOLITE.

BY

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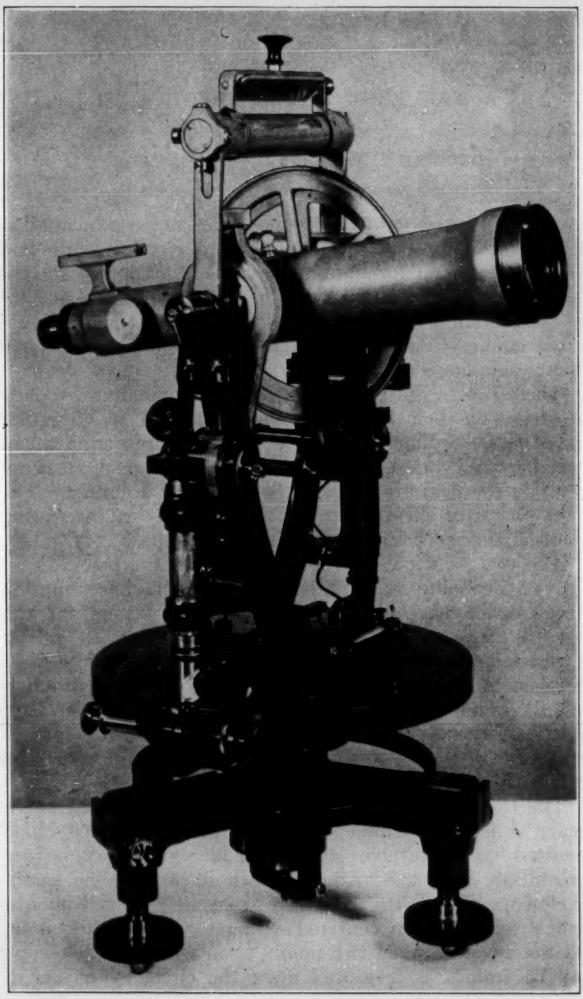
A RAPID increase in land values, the increase in number and magnitude of public and private engineering works and the greater demand for maps of all parts of the country and the coast by a mobile population, has created a necessity for the completion at an early date of the precise control surveys of the country, on which are based the coastal charts and topographic maps of the interior.

These precise surveys, technically designated as Geodetic by virtue of their taking into consideration the irregular curved figure of the earth, are performed with instruments of special accuracy, designed for the purpose, by which measurements in the field are made with laboratory accuracy. The development of these instruments presents some interesting scientific and mechanical engineering problems.

The two principal instruments used are the precise level and the theodolite, the first being used in the determination of exact differences in elevation and the second for the accurate measurement of the angles of the triangles laid off in trigonometric surveys. The theodolite is by far the more complicated of the two and as its design and construction embody practically all the problems involved in the level as well as those peculiar to itself, this instrument only, as developed by the U. S. Coast and Geodetic Survey, will be described in this article.

The theodolite is purely an angle measuring device. In theory it is quite simple, consisting of a graduated circle mounted on a suitable leveling head which may be set horizontally in a fixed azimuth with respect to the earth. A telescope fitted with cross wires may be revolved upon a vertical axis which is centered with reference to this circle, and the angle between two points upon which the telescope may be trained is measured upon the circle by means of

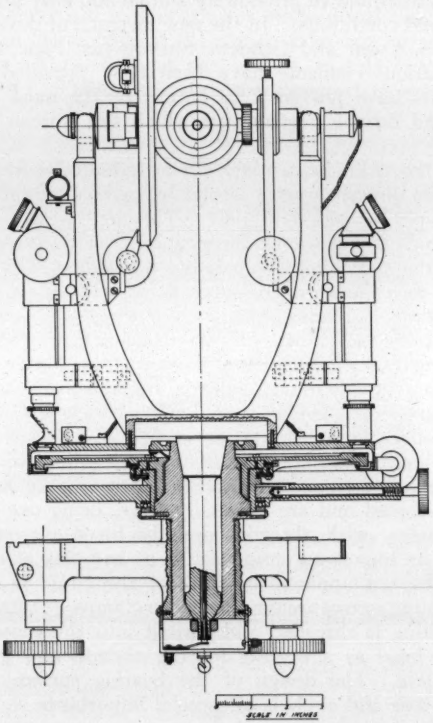
FIG. 1.



suitable micrometer microscopes attached to the telescope standard.

To design and construct an instrument which will accomplish this angular measurement with the necessary refinement

Fig. 2.



is considerably more of a problem than would appear from the above description. The mechanical fit of various parts must be of the closest and there are certain elements of design which vitally affect the quality of the finished instru-

ment. For instance, there must be no appreciable change in the fit of the vertical axis bearing due to changes in temperature and there must be no frictional drag between the telescope element, or alidade, and the graduated circle. The entire design must be made with a view to ruggedness and speed of manipulation and to provide for simple and easy adjustment under field conditions. In the new instrument developed by the U. S. Coast and Geodetic Survey (see Figs. 1 and 2), these various elements have been fully provided for and field tests have proven it to be one of the most accurate, rapid and durable instruments which the Bureau has ever used.

The theodolite has a 9-inch circle graduated to five minutes and reads directly to one second by each of two micrometer microscopes located 180° apart. The circle is of the floating type, which means that its bearing is entirely separated from that of the alidade and that it has no clamp. It is read by vertical micrometer microscopes fitted with angle eyepieces to facilitate observation.

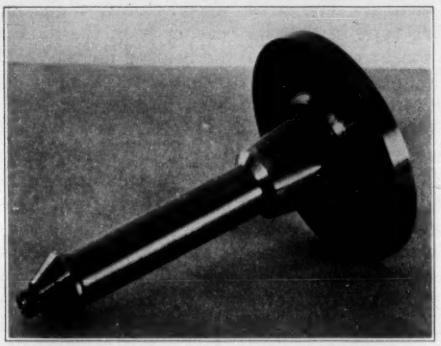
The telescope is of the internal focusing type, which assists in making it dust and moisture proof, and has a large objective to admit a maximum of light, a valuable consideration in night surveying. A ten-second, six-inch circle is mounted in the usual manner for vertical angle measurements.

The leveling head is of a stiff aluminum alloy, and is of the three armed design. The leveling screws have a medium pitched thread and are unusually large, being one-half inch in diameter, with threads carefully fitted into the head casting, an important consideration as any play at this point may cause an apparent shifting of the circle in azimuth. The leveling screws are provided with clamps. A fine grained iron casting is threaded and shrunk into the center of the leveling head as a bearing for the alidade and graduated circle plate. The design of the bearing surfaces of both vertical axis and circle is of especial importance as it is here that changes in fit due to changes in temperature may cause serious error. If the bearings become too tight, too great an effort is necessary to turn the alidade and may cause a shifting of the instrument in azimuth with resultant error in reading. On the other hand, too loose a fit will cause a wobbling of the

alidade, which is certain to result in errors. In the customary single-cone type of vertical axis for such instruments, a vertical thrust adjustment is usually furnished and some instruments require frequent adjustment of this device.

These changes in fit are automatically compensated for in the new theodolite by an inherent characteristic of the design in that the vertical axis bearing is made up of two conical surfaces, an acute cone at the top to take care of sideways fit and an obtuse cone at the bottom to take up thrust. (See Fig. 3.) These two cones are designed to meet at a

Fig. 3.



common apex and in consequence the bearing elements of axis and socket are parts of similar triangles and regardless of differences of temperature coefficient, expansion or contraction both laterally and longitudinally are always in proportion and the fit is maintained. The same type of bearing is used for the horizontal circle, although its use for this element is not so important.

The vertical axis is a forging of unhardened, high grade, tool steel, the part being left unhardened in order to avoid the setting up of internal stresses in hardening which might eventually release themselves and cause warping. The axis is pierced with a small hole which permits of the introduction

of an insulated electrical conductor. This conductor is brought to an insulated terminal at the lower end of the axis through which contact is made by a spring brush and binding post, the other side of the circuit being grounded. This arrangement permits of the use of any suitable source of electric current for the various small bulbs used for lighting cross wires, microscopes, etc., and does away with the mounting of flashlight batteries on the alidade, an objectionable feature of previous instruments used by the Bureau.

The circle plate is of bronze, with a sterling silver ring upon which the graduations are ruled. A smaller circle of coarse, one degree graduations is ruled upon the bronze for a rough setting. The circle, as previously mentioned, is of the floating type in that its bearing is on the outside of the cast iron socket which is also the bearing for the alidade axis. Great care must be taken that this bearing shall be concentric with that of the vertical axis as any considerable lack of concentricity will result in a large difference in the readings of the two micrometers on part of the circle, and make it more difficult to compute the mean value of the readings. The circle is held against its seat by gravity and by a large spring washer and nut.

The standard is in one piece of cast bronze, with ell-shaped sections to give a maximum of rigidity with a minimum of weight. The vertical axis fits tightly in a carefully machined socket in the standard and is held by four large steel screws so that axis and standard are virtually one piece.

The micrometer microscopes are of the design in which the actuating screw is pointed and thrusts against a rigid bearing inside of the micrometer box with the slide reacting against it by virtue of two light tension springs. It has been the experience of the U. S. Coast and Geodetic Survey that this is the most satisfactory of the designs it has tried as the pointed thrust bearing, being inside the box, is protected from dirt and cannot readily be responsible for any endwise motion of the screw due to eccentricities, which would introduce serious errors in the readings. Furthermore, the tension spring reactance is considered to be more sensitive and not liable to cause any irregular jumping of the slide

as may be the case in the use of a compression spring if it shifts position, even slightly.

A unique feature of the micrometer is the use of a graduated drum of glass, either milk colored or clear with a frosted interior (see *Journal of the Franklin Institute* for September, 1927). As all work is done at night in order to minimize the effects of horizontal atmospheric refraction due to heated air currents, this drum, provided with a small electric bulb to light its interior, is very desirable, as the etched and blackened graduations stand out boldly. The intensity of illumination may also be easily regulated so that there need not be as much fatigue of the observer's eye as in the past, due to looking at a faint light and then immediately at a brilliantly lighted micrometer drum.

The alidade clamp and slow motion tangent screw have several unusual features of design. The clamp is mounted on a large thrust ball bearing which practically does away with friction at this point, making pointing of the telescope correspondingly easier and smoother. (Note: The telescope is approximately 45 power and consequently of restricted field of view.) The clamp is of the radial type so that the act of clamping has no tendency to rotate the alidade as in the tangential design. The clamp is very powerful, having a shoe pressed against the braking surface by a thumb screw. Upon release, the screw withdraws the shoe positively so that there is no possibility of drag and friction. The slow motion tangent screw is unique in that it actuates a plunger which does not rotate. This non-rotary feature prevents the irregular motion of the alidade caused by an eccentric point on a rotary tangent screw pressed against the lug on the alidade, and the design lends itself to dust proofing, a valuable feature as the screw must be of fine pitch.

The complete instrument is quite light, weighing but $34\frac{1}{2}$ pounds. It is rugged and easy to adjust, fast in operation and has proven itself to be as accurate as any that have been used by the Bureau. These are the features which were specifically laid down as necessary when the design of the theodolite was taken up as being in their entirety unobtainable in any one commercial instrument. The field results have demonstrated that these requirements have been amply fulfilled.

Ionization in the Upper Atmosphere of the Earth. E. O. HULBURT. (*Phys. Rev.*, June, 1928.) There are five agencies that may produce ionization in the upper part of the atmosphere of the earth, ionizing radiation from the earth, cosmic radiation and, from the sun, alpha and beta particles and ultra-violet light. The first may be neglected because in the lower strata of the air an increase of distance from the earth is accompanied by an increase of ionization. Cosmic radiation at the surface of the earth produces but few ions and high up where the air is rare it can have little effect. There is no positive evidence that the earth receives alpha and beta particles from the sun, but without any question its ultra-violet radiation does reach the earth.

The author combines theory and the experimental results of others and reaches the conclusion that much of the ionization in the higher part of the atmosphere is due to ultra-violet light of wave-length less than 1200 A. and that on a summer's day most of the ions are produced above the 200 km. level. The sun sends to the earth enough radiation of the effective wave-length to produce 2×10^8 pairs of ions every sec. in an air column 1 sq. cm. in cross-section reaching up from an altitude of 200 km. to the outer limit of the atmosphere. On a summer day the density of electrons so caused is a maximum at a height of 190 km. and amounts to 3×10^5 electrons per cu. cm. "This ionization is shown to explain quantitatively many facts of wireless telegraphy, i.e., the skip distances, overhead absorption coefficients, limiting waves, ranges and the apparent heights reached by waves." The change of wireless signals with hour and season can likewise be explained by the author's theory. The non-polar aurora of Rayleigh is attributed to solar energy stored in the upper air in ionized or excited atoms and set free later as light. G. F. S.

THE EQUATION OF STATE OF A SUBSTANCE AT THE ABSOLUTE ZERO OF TEMPERATURE, AND PROPERTIES CONNECTED WITH IT.

BY

R. D. KLEEMAN, B.A., D.Sc.

§ 1. INTRODUCTORY REMARKS.

IN previous papers [1] the writer has determined the zero of the controllable internal energy and entropy of a substance, and some of the corresponding properties. This zero corresponds to the substance being in the condensed state under its vapor pressure at the absolute zero of temperature. The subject is extended in the present paper in connection with the equation of state of a substance at the absolute zero of temperature. It leads to results which can be tested by numerical data. The equation of state thus obtained thermodynamically falls into line with the equation of state of a mixture at any temperature obtained in a previous paper,[2] whose deduction does not depend on thermodynamics.

§2. PROPERTIES OF A SUBSTANCE OR MIXTURE IN CONNECTION WITH ITS MAXIMUM WORK AT THE ABSOLUTE ZERO OF TEMPERATURE.

If A denotes the maximum work and p the pressure of a substance or mixture, their relation is given by the well known equation

$$\left(\frac{\partial A}{\partial v}\right)_T = -p. \qquad (1)$$

On multiplying it by ∂v and integrating we obtain

$$A = -\int p \cdot \partial v + \phi(T, M_a, M_b, \cdots), \qquad (2)$$

where ϕ is an arbitrary function of the temperature and

[1] *J. Phys. Chem.*, 31, 747; 31, 937 (1927): *Phil. Mag.*, 3, 883; 4, 257 (1927); 5, 668 (1928).

[2] J. FRANKLIN INST., 206, (4), 511 (1928).

masses $M_a, M_b, \cdots$ in mols of the constituents. The maximum work is also given by

$$A = U - TS, \tag{3}$$

where U denotes the internal energy and S the entropy of the substance. On substituting from this equation for A in the preceding equation and differentiating it with respect to M_a at constant volume and temperature we obtain

$$\left(\frac{\partial U}{\partial M_a}\right)_{v,\,T} - T\left(\frac{\partial S}{\partial M_a}\right)_{v,\,T} = -\int\left(\frac{\partial p}{\partial M_a}\right)_{v,\,T}\cdot\partial v + \left(\frac{\partial \phi}{\partial M_a}\right)_{v,\,T}. \tag{4}$$

The left-hand side can be shown to be zero if the substance is under its vapor pressure at the absolute zero of temperature.

We may write

$$\frac{dU}{dM_a} = \left(\frac{\partial U}{\partial v}\right)_T \frac{dv}{dM_a} + \left(\frac{\partial U}{\partial M_a}\right)_v \tag{5}$$

according to the Calculus. Now

$$\left(\frac{\partial U}{\partial v}\right)_T = T\left(\frac{\partial p}{\partial T}\right)_v - p = 0 \tag{6}$$

according to a well-known thermodynamical equation, since $T = 0$ and $p = 0$. The coefficient dU/dM_a expresses the change in internal energy when a mass of the mixture under its vapor pressure is mixed with a mass ∂M_a of the elementary substance a under its vapor pressure, and the resultant mixture is under its vapor pressure. This change the writer has shown is zero at the absolute zero of temperature.[3] It follows therefore from equation (5) that

$$\left(\frac{\partial U}{\partial M_a}\right)_v = 0. \tag{7}$$

From this equation, and since $T = 0$, it follows that the left-hand side of equation (4) is zero or

[3] *J. Phys. Chem.*, 31, 1559 (1927).

$$\left(\frac{\partial A}{\partial M_a}\right)_{v,\,T} = -\int\left(\frac{\partial p}{\partial M_a}\right)_{v,\,T}\cdot\partial v + \left(\frac{\partial \phi}{\partial M_a}\right)_{v,\,T} = 0. \quad (8)$$

This equation may be transformed into a more useful form.

The maximum work has the functional form expressed by the equation

$$A = M_a\cdot\psi_a\left(T, \frac{M_a}{v}, \frac{M_b}{v}, \cdots\right) + M_b\cdot\psi_b\left(T, \frac{M_a}{v}, \frac{M_b}{v}, \cdots\right)\cdots + M_a\cdot\xi_a(T) + M_b\cdot\xi_b(T) + \cdots \quad (9)$$

or

$$A = \Sigma M\cdot\psi\left(T, \frac{M_a}{v}, \frac{M_b}{v}, \cdots\right) + \Sigma M\cdot\xi(T), \quad (10)$$

since it satisfies the condition that if the masses of each constituent and the volume are increased n times under constant pressure the maximum work is increased n times. Equation (2) may therefore be written

$$A = -\int p\cdot\partial v + \Phi(T, M_a, M_b, \cdots) + \Sigma M\cdot\xi(T), \quad (11)$$

where

$$-\int p\cdot\partial v + \Phi(T, M_a, M_b, \cdots) = \Sigma M\cdot\psi\left(T, \frac{M_a}{v}, \frac{M_b}{v}, \cdots\right). \quad (12)$$

according to equation (10). On differentiating equation (11) with respect to M_a at constant volume, and applying it to a substance under its vapor pressure at the absolute zero of temperature, it becomes

$$\left[\frac{\partial}{\partial M_a}\{-\int p\cdot\partial v + \Phi(0, M_a, M_b, \cdots)\}\right]_v + \left(\frac{\partial}{\partial M_a}(\Sigma M\cdot\xi(0))\right)_v = 0, \quad (13)$$

according to equation (8). The two expressions in this equation must separately vanish since M_a, M_b, $\cdots$, are independent variables, and the differential coefficient of the expression within the square brackets is according to equation (12) a function of T, M_a/v, M_b/v, $\cdots$. Hence generalizing we have

$$\left.\begin{aligned} &\frac{\partial}{\partial M_a}\{-\int p\cdot\partial v+\Phi(0, M_a, M_b, \cdots)\}=0,\\ &\frac{\partial}{\partial M_b}\{-\int p\cdot\partial v+\Phi(0, M_a, M_b, \cdots)\}=0,\\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\end{aligned}\right\} \tag{14}$$

when $T = 0$ and initially $p = 0$, where the differentiations refer to the volume and temperature being kept constant.

§3. THE EQUATION OF STATE OF A SUBSTANCE OR MIXTURE AT THE ABSOLUTE ZERO OF TEMPERATURE.

This equation is obtained if a form of the function ψ in equation (12) is found which satisfies equations (14). Let us write

$$\begin{aligned} -\int p\cdot\partial v+\Phi(0, M_a, M_b, \cdots)&\\ =v\Sigma\frac{M}{v}\cdot\psi\left(0, \frac{M_a}{v}, \frac{M_b}{v}, \cdots\right)&\\ =v\cdot\psi_1\left(\frac{M_aA_0+M_aB_0+\cdots}{v}\right)=v\cdot\psi_1(x)\cdots& \end{aligned} \tag{15}$$

according to equation (12) applied to $T = 0$ and $p = 0$, where ψ_1 is a proposed functional form of $\Sigma(M/v)\cdot\psi$ involving

$$\frac{M_aA_0+M_bB_0+\cdots}{v}$$

written for shortness x, where A_0, B_0, C_0, $\cdots$ are constants. From the first of equations (14) and equation (15) we then have

$$A_0\frac{\partial\psi_1}{\partial x}=0$$

and from the second of equations (14) and equation (15)

$$B_0 \frac{\partial \psi_1}{\partial x} = 0$$

and so on. Thus if ψ_1 the proposed form of $\Sigma(M/v) \cdot \psi$ satisfies one of equations (14) it satisfies each of them. The function ψ_1 has thus the correct *general* form.

The relation between p, v, M_a, $\cdots$ at $p = 0$ and $T = 0$ is obtained on differentiating equation (15) partially with respect to v, which may be written

$$p = \psi_1(x) + v \frac{\partial \psi_1}{\partial v} = \psi_0\left(\frac{M_a A_0 + M_b B_0 + \cdots}{v}\right). \quad (16)$$

This is also the equation of state at $T = 0$ corresponding to various values of p and v, since in general p is a function of M_a/v, M_b/v, $\cdots$ and the general equation of state assumes the foregoing form for a value of v corresponding to $p = 0$. The equation satisfies equations (14) as should be the case. It has a certain characteristic form from which a number of important properties of matter at the absolute zero of temperature may be deduced.

§4. A CHARACTERISTIC CONSTANT OF A SUBSTANCE.

On writing the masses of the constituents equal to zero except M_a in equation (16) it becomes

$$p_a = \psi_0\left(\frac{M_a A_0}{v}\right) \quad (17)$$

and is the equation of state of the pure substance a at $T = 0$. At the absolute zero of control, which corresponds to the substance being under its vapor pressure at $T = 0$, the equation becomes

$$p_{a0} = 0 = \psi_0\left(\frac{M_a A_0}{v_{a0}}\right), \quad (18)$$

where v_{a0} denotes the volume of the substance under its zero vapor pressure p_{a0}. From this equation it follows that

$$\frac{M_a A_0}{v_{a0}} = k, \quad (19)$$

where k is a constant. Similarly it can be shown that

$$\frac{M_b B_0}{v_{b0}} = k \tag{20}$$

and so on. *Thus k is an absolute constant, and is one of the important constants in nature.*

On writing equation (19) in the form

$$A_0 = \frac{v_{a0}}{M_{aa}} k \tag{21}$$

it appears that the characteristic constant A_0 of a substance at the absolute zero of temperature is proportional to the atomic volume v_{a0}/M_a, or the volume occupied by one gram atom, at the absolute zero of control.

§5. THE ADDITIVE NATURE OF THE ATOMIC VOLUMES OF THE CONSTITUENTS OF A MIXTURE AT THE ABSOLUTE ZERO OF CONTROL.

If a mixture is under its vapor pressure at $T = 0$ it follows from equation (16) similarly as before that

$$\frac{M_a A_0 + M_b B_0 + \cdots}{v_0} = k, \tag{22}$$

where v_0 denotes the volume of the mixture under these conditions. On eliminating the masses of the constituents by equations of the type (19) the foregoing equation becomes

$$v_{a0} + v_{b0} + \cdots = v_0 \tag{23}$$

or the volume of a mixture at the absolute zero of control is equal to the volumes the constituents have in the isolated state.

This result is well sustained by the facts. Thus Traube has shown [4] that the volume of a substance in the condensed state at the absolute zero of temperature is equal to the sum of the volumes of the constituents in the isolated state, and that the volume of an atom is proportional to the square root of its atomic weight. This is shown for a number of substances in the Table given compiled from a Table given by

[4] *Physik. Z.*, 667, 1909.

Traube. The second column gives the molecular volumes per mol. of a number of substances obtained by extrapolation by means of Cailletet and Mathias linear diameter law, and the third column gives the ratios obtained by dividing the molecular volumes of a substance by the corresponding sum of the square roots of the atomic weights, which, it will be seen, are approximately constant. Traube deduced from the extensive data he examined that for a mol. of atoms a

$$v_{a0} = 2.6\sqrt{a_\omega}, \qquad (24)$$

where a_ω denotes the atomic weight of the atom in terms of that of the hydrogen atom. Since according to Glasson the square root of the atomic weight is approximately proportional to the two-thirds power of N the atomic number, the ratio $v_{a0}/N^{2/3}$ is also approximately constant.

It appears therefore that the characteristic constant A_0 of a substance a is proportional to the square root of its atomic weight, or proportional to the 2/3 power of its atomic number.

The deductions in this paper, which have just received an interesting numerical confirmation, are based fundamentally on equation (7). This equation in turn is based [5] on the controllable internal energy of a substance being zero under its vapor pressure, and that $(\partial S/\partial T)_v = 0$, when $T = 0$, results which were established [6] in a previous paper. These results were deduced theoretically from thermodynamics, and now receive additional numerical confirmation. It may also be noted that the results $c_v = 0$ and $(\partial c_v/\partial T)_v = 0$ deduced previously, where c_v denotes the specific heat at constant volume, depend on the equation $(\partial S/\partial T)_v = 0$.

In a previous paper it was shown [2] that the equation of state of a complex substance at the temperature T has the form

$$p = \psi\left(\frac{M_aA_1 + M_bB_1 + \cdots}{v}, \frac{M_aA_2 + M_bB_2 + \cdots}{v}, \cdots\right),$$

where $A_1, B_1, \cdots A_2, B_2, \cdots, \cdots$ are functions of T. A comparison of this equation with equation (16) shows that when

[5] *J. Phys. Chem.*, 31, 1563 (1927).
[6] *J. Phys. Chem.*, 31, 747 (1927).

$T = 0$ we have

$$\frac{A_1}{r_1} = \frac{A_2}{r_2} = \frac{A_3}{r_3} = \cdots A_0,$$

$$\frac{B_1}{r_1} = \frac{B_2}{r_2} = \frac{B_3}{r_3} = \cdots B_0,$$

etc., where r_1, r_2, $r_3 \cdots$ are numerical constants.

§6. THE RATIO OF VAPOR PRESSURES AT $T = 0$.

Equations (17) and (16) which apply to a mixture and the isolated substance a under their vapor pressures at $T = 0$ may be written

$$p = \psi_0(k), \tag{25}$$

$$p_a = \psi_0(k), \tag{26}$$

by means of equations (19) and (22), and hence

$$p/p_a = 1. \tag{27}$$

Thus though the vapor pressures are zero the ratio of one to the other is finite and equal to unity, and this will evidently hold for any substance and mixture. It follows from this result that substances mix in all proportions at the absolute zero of temperature.

§7. THE PRESSURE AT ANY GIVEN STATE AT $T = 0$.

Equations (16) and (17) which also apply to matter in any state at $T = 0$ may be written

$$p = \psi_0\left(\frac{kv_0}{v}\right), \tag{28}$$

$$p_a = \psi_0\left(\frac{kv_{a0}}{v}\right), \tag{29}$$

by means of equations (19) and (22). Therefore if unit volumes of the substance a and the mixture are considered corresponding to $p = 0$, or that $v_0 = 1$ and $v_{a0} = 1$, the equations of state become the same. Thus as far as pressure and volume relations are concerned all substances and mixtures behave in the same manner at the absolute zero of temperature.

But the densities are not the same. Thus the density ρ_{a0} of the substance a at $p = 0$ and $T = 0$ is given by

$$\rho_{a0} = \frac{\omega_a}{2.6\sqrt{\omega_a}} = \frac{\sqrt{\omega_a}}{2.6}, \tag{30}$$

according to equation (24), and hence increases with the atomic weight. The density of a mixture is given by

$$\rho_0 = \frac{\Sigma n \omega_a}{2.6 \Sigma n \sqrt{\omega_a}}. \tag{31}$$

§8. THE COEFFICIENTS OF COMPRESSION AND MASS ADDITION AT $T = 0$.

The coefficient of compression is given by

$$\beta = -\frac{\partial v}{\partial p}\frac{1}{v}. \tag{32}$$

For the two cases whose equations of state are (28) and (29) we have

$$\beta = \frac{1}{\dfrac{\partial \cdot \psi_0\left(\dfrac{kv_0}{v}\right)}{\partial v}}\frac{1}{v}, \tag{33}$$

$$\beta_a = \frac{1}{\dfrac{\partial \cdot \psi_0\left(\dfrac{kv_{a0}}{v}\right)}{\partial v}}\frac{1}{v}. \tag{34}$$

Therefore if masses of the substances are taken so that the volumes v_0 and v_{a0} are equal to one another, the coefficients of compression are the same if the volumes of the substance a and of the mixture are taken equal to each other, and this result therefore holds in general.

The coefficient of mass addition γ, corresponding to the addition of a mass ∂M_a in gram atoms of the substance a, at constant volume, is given by

$$\gamma = \left(\frac{\partial p}{\partial M_a}\right), \tag{35}$$

where M_a denotes the mass in gram atoms, which the substance or mixture contains. By the help of equations (16), (17), (19), and (22) we then have

$$\gamma = \left(\frac{\partial \psi_2(y)}{\partial y}\right)_v \frac{A_0}{v}, \tag{36}$$

$$\gamma_a = \left(\frac{\partial \psi_2(z)}{\partial z}\right)_v \frac{A_0}{v}, \tag{37}$$

where

$$y = \frac{kv_0}{v}$$

and

$$z = \frac{kv_{a0}}{v},$$

for a pure substance a and a mixture. Therefore if masses of matter are considered so that v_0 is equal to v_{a0} the coefficients will be the same for equal volumes of the substance and mixture.

If γ_a denotes the coefficient when the substance a is added, and γ_e that when the substance e is added, to any given mixture whose volume is unity when under its vapor pressure at $T = 0$, we have

$$\frac{\gamma_a}{\gamma_e} = \frac{A_0}{E_0}, \tag{38}$$

§9. THE WORK OF COMPRESSION AND CHANGE IN INTERNAL ENERGY AT $T = 0$

The work ω done in compressing a mixture from its volume v_0 under its vapor pressure to the volume v may be written

$$\omega = \int_{v_0}^{v} p \cdot \partial v = \psi_3\left(\frac{kv_0}{v}\right)\frac{v^2}{kv_0} - \psi_3(k)\frac{v_0}{k}, \tag{39}$$

taking into account equations (16) and (22). Thus the work does not depend on the nature of the mixture but only on its initial and final volume. If equation (6) is multiplied by ∂v and integrated between the same limits the corresponding change in internal energy is obtained. Since $T = 0$ this change is equal to $-\omega$.

§10. THE HEAT AND WORK OF EVAPORATION AT $T = 0$.

If the result of the previous Section is applied to obtain the work performed during the evaporation of a mixture, we have

$$\omega = \psi_3\left(\frac{kv_0}{\infty}\right)\frac{\infty^2}{kv_0} - \psi_3(k)\frac{v_0}{k},$$

which may be written

$$\omega = k_1 v_0 + k_2,$$

where k_1 and k_2 are absolute constants. But ω is zero since it is of the form ΣMRT, and hence k_1 and k_2 are zero. k_1 and k_2 are evidently the limiting values of functions of T when $T = 0$. Therefore if we write the equation in the form

$$\frac{\omega}{k_2} = \frac{k_1}{k_2}v_0 + 1,$$

the limiting values of ω/k_2 and k_1/k_2 are finite. If however we are dealing with an infinitely small mass of the mixture we have $v_0 = 0$ and the limiting value of ω/k_2 is now zero. This reduces the foregoing equation to $0 = 1$, which is absurd. Hence the quantity k_2 must be neglected in comparison with the quantities ω and $k_1 v_0$, which reduces the equation to

$$\omega = k_1 v_0. \tag{40}$$

On considering the evaporation of the isolated constituent a we have

$$\omega_a = k_1 v_{a0}. \tag{41}$$

This and the preceding equation give

$$\frac{\omega}{\omega_a} = \frac{v_0}{v_{a0}} \tag{42}$$

or the ratio of the works of evapoartion, which is a finite quantity.

In a previous paper[7] it is shown that

$$L + \omega = 0, \tag{43}$$

[7] J. FRANKLIN INST., 206, (5), 691 (1928).

where L denotes the internal heat of evaporation. For a mixture and a pure substance a we have from equations (43) and (42)

$$\frac{L}{L_a} = \frac{v_0}{v_{a0}}, \tag{44}$$

which gives the ratio of the internal heats of evaporation. This ratio is of importance since in the paper quoted it is shown that the heat of evaporation is zero.

§11. THE ZERO OF THE INTERNAL ENERGY OF A SUBSTANCE OR MIXTURE UNDER CONSTRAINT.

Suppose that a substance or mixture is subjected under all conditions to a constraint such as a constant magnetic field, or a constant electric field. It can easily be shown that the zero of internal energy under these conditions corresponds to the substance or mixture being under its vapor pressure at the absolute zero of temperature, as is the case when there is no constraint acting.[6] It can also be shown similarly as when no constraint is acting,[5] that no change in internal energy takes place on mixing the substances under their vapor pressures at the absolute zero of temperature. Hence the particular internal energy due to the field is not changed on mixing. The internal energy U can also be shown to possess the property that

$$\frac{dU}{dT} = 0, \tag{45}$$

$$\frac{d^2U}{dT^2} = 0, \tag{46}$$

Since these equations also hold when the substances are not subjected to a constraint,[8] they hold also for the particular internal energy due the presence of a constraint. By means of these results additional properties of substances at $T = 0$ may be deduced.

§12. MAGNETIC PROPERTIES.

According to the preceding section no change takes place in the magnetic energy, or in the part of the internal energy

[8] *J. Phys. Chem.*, 31, 937 (1927).

due to the presence of the magnetic field, on mixing a number of substances in a magnetic field of strength H at $T = 0$. Hence if two substances a and e of permeability μ_{a0} and μ_{e0} are mixed, giving rise to a mixture of permeability μ_{ae0}, we have

$$\frac{H^2\mu_{ae0}v_0}{8\pi} = \frac{H^2\mu_{a0}v_{a0}}{8\pi} + \frac{H^2\mu_{e0}v_{e0}}{8\pi}$$

or

$$\mu_{ae0}v_0 = \mu_{a0}v_{a0} + \mu_{e0}v_{e0}. \tag{47}$$

We also have

$$v_0 = v_{a0} + v_{e0}, \tag{48}$$

according to Section 5, where v_{a0}, v_{e0}, and v_0 denote respectively the volumes of the constituents and of the mixture under their vapor pressures at $T = 0$. Thus the permeability of the mixture at the absolute zero of temperature can be calculated from the permeabilities of the constituents by means of the foregoing two equations.

The particular internal energy of a substance which does not depend on its volume and temperature is the internal energy possessed by the substance under its vapor pressure at $T = 0$. Hence the magnetic internal energies $H^2\mu_{ae0}v_0/8\pi$, etc., at $T = 0$, are parts of the corresponding magnetic internal energies of the substances at T which do not change with v and T, but which disappear when the magnetic field is removed.

If μ_a, μ_e, and μ_{ae} denote the permeabilities corresponding to any volume and temperature the magnetic internal energies $H^2\mu_{ae}v/8\pi$, etc., satisfy equations (45) and (46). Hence

$$\frac{d\mu_{ae}}{dT} = 0. \tag{49}$$

$$\frac{d^2u_{ae}}{dT^2} = 0, \tag{50}$$

for the mixture at $T = 0$, since[8] $dv/dT = 0$ and $dv^2/dT^2 = 0$, and similar equations hold for the constituents a and e. The relations (47), (48), (49), and (50) could be tested experimentally by extrapolating magnetic measurements down to $T = 0$.

§13. PROPERTIES OF INDUCTIVITY.

If the substances in the preceding Section were subjected to an electric field of intensity ρ instead of a magnetic field similar conclusions would hold. We would then have

$$\frac{2\pi\rho^2 v_0}{K_{ae0}} = \frac{2\pi\rho^2 v_{a0}}{K_{a0}} + \frac{2\pi\rho^2 v_{e0}}{K_{e0}}$$

or

$$\frac{v_0}{K_{ae0}} = \frac{v_{a0}}{K_{a0}} + \frac{v_{e0}}{K_{e0}}, \tag{51}$$

where K_{ae0}, K_{a0}, and K_{e0} denote the inductivities of the mixture and isolated constituents respectively at $T = 0$. As before we have besides

$$v_0 = v_{a0} = v_{e0}, \tag{52}$$

By means of the foregoing two equations the inductivity of the mixture may be calculated from the inductivities of the constituents.

It can now easily be shown similarly as in the preceding Section that

$$\frac{dK_{ae}}{dT} = 0, \tag{53}$$

$$\frac{d^2K_{ae}}{dT^2} = 0 \tag{54}$$

for the mixture at $T = 0$, and that similar equations hold for the isolated constituents.

§14. MIXING SUBSTANCES UNDER A PRESSURE p AT $T = 0$.

Consider a number of substances under the same external pressure p at $T = 0$. From equations (28) and (29) it follows that the corresponding volumes are the same fraction α of their volumes at $p = 0$. The work done on compressing a mixture from the pressure 0 to p is

$$\omega = \left\{\psi_3\left(\frac{k}{\alpha}\right)\alpha - \psi_3(k)\right\} v_0 \tag{55}$$

according to equation (39). Since v_0 is equal to the sum of

the volumes of the isolated constituents at $p = 0$ and $T = 0$ according to equation (23), the above work is equal to the sum of the work of compressing the isolated constituents. A similar result holds for the changes in internal energy. Hence, since the work of mixing a number of substances, and the corresponding change in internal energy, at $p = 0$ and $T = 0$, is zero, this will also hold if p has some finite value. This can easily be demonstrated by passing the mixture through a cycle using the foregoing results.

§15. THE RADIATION PROPERTIES OF SUBSTANCES AT $T = 0$.

TABLE

Substance		v_0	$v_0/\Sigma n\sqrt{\omega_a}$
Iodo benzene	C_6H_5I	89.9	2.4
Chloro benzene	C_6H_5Cl	79.0	2.5
Fluor benzene	C_6H_5F	70.6	2.3
Bromo benzene	C_6H_5Br	82.2	2.4
Stannic chloride	$SnCl_4$	87.0	2.5
Carbon tetrachloride	CCl_4	72.7	2.7
Titanium trichloride	$TiCl_3$	85.8	2.8
Phosphorous oxychloride	$POCl_3$	70.1	2.6
Arsenic trichloride	$AsCl_3$	65.4	2.3
Ethyl sulphide	$C_4H_{10}S$	80.8	2.7
Benzene	C_6H_6	66.4	2.5
Octane	C_8H_{18}	123.5	2.7
Tentane	C_6H_{12}	80.7	2.7
Ethyl ether	$C_4H_{10}O$	72.6	2.6
Acetone	C_3H_6O	53.2	2.6
Ethyl acetate	$C_4H_8O_2$	72.6	2.4
Sulphur dioxide	SO_2	31	2.3
Carbon dioxide	CO_2	25.5	2.2

Suppose that the substances a and e and the mixture that may be formed of them are subjected to a radiation of intensity I, and let P_a, P_e, and P_{ae} denote the radiation pressures respectively exerted on them per cm^2. On mixing the substances a and e at $T = 0$ no external work is done according to Section 14, and hence

$$P_{ae}v_0 = P_a v_{a0} + P_e v_{e0}. \tag{56}$$

Since

$$\left.\begin{aligned} P_{ae} &= \tfrac{1}{3}a_{ae}\mathrm{I}, \\ P_a &= \tfrac{1}{3}a_a\mathrm{I}, \\ P_e &= \tfrac{1}{3}a_e\mathrm{I}, \end{aligned}\right\} \tag{57}$$

where a_a, a_e, and a_{ae} denote the absorbing powers of the substances a and e and of the mixture respectively, equation (56) may be written

$$a_{ae}v_0 = a_a v_{a0} + a_e v_{e0}. \tag{58}$$

Besides we have the equation

$$v_0 = v_{a0} + v_{e0}. \tag{59}$$

From these two equations the absorbing power of the mixture at $T = 0$ may be expressed in terms of the absorbing powers of the isolated constituents. The foregoing results will evidently hold independently of the nature of the radiation.

SCHENECTADY, N. Y.

THE PROGRESS OF 220 K.V. DEVELOPMENT.

BY

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"THERE are no bounds (but what expense and labor give) to the force men may raise and use in the electrical way," said Benjamin Franklin in his work entitled "New Experiments and Observations on Electricity."

It was in Philadelphia that the idea of transmitting electricity over a distance was first conceived, and Franklin thus describes his epoch-making experiment: "Two iron rods about 3 feet long were planted just within the margin of the Schuylkill River on the opposite sides. A thick piece of wire with a small round knob at its end was fixed on the top of one of the rods bending downwards, so as to deliver commodiously the spark upon the surface of the spirit. A small wire, fastened by one end to the handle of the spoon containing the spirit, was carried across the river and supported in the air by the rope commonly used to hold by in drawing ferryboats over. The other end of this wire was tied around the coating of the bottle, which being charged the spark was delivered from the hook to the top of the rod standing in the water on that side. At the same instant the rod on the other side delivered the spark into the spoon and fired the spirit. The electric fire returned to the coating of the bottle through the handle of the spoon and the supported wire connected with them."

Today Philadelphia is supplied with power from the largest interconnected power system in the world employing 220 kilovolt equipment. Benjamin Franklin, who first conceived the possibility of electricity being sent to distant points, speaks of the proposed experiments of "sending electric fire (electricity) through a vast length of space." One hundred and seventy years later we find the country provided with isolated power systems and a new industry of power production created. Individual systems are now in existence using steam or hydraulic prime movers and employ-

ing transmission from 22,000 up to 220,000 volts. Today electric power is essential to production of raw material and is a powerful aid in transportation, also in the utilization of products of industry. The electric system is in itself a complete unit for the production, transmission and distribution of energy. It may be said that a nation's civilization can be largely measured in terms of k.w. hours consumed per capita, for as the electric energy consumption is large so the inefficient human labor energy will be small.

Fig. 1.

Conowingo Station. Night view looking north showing power house 220kv substation and west portion of dam.

Ideas conceived one hundred and seventy years ago as a possibility, when little was known of the newly discovered phenomenon—electricity—have become not only a reality but a matter of necessity. The trend of electrical development was foreshadowed by Franklin in his early experiments. He says, "We fire spirits, we light candles, we represent lightning, we electrify a person, we melt gold, silver and copper in small quantities by the electrical flash. We have frequently given polarity to needles and reversed it at pleasure. We demonstrate the afflux and efflux of electrical fire by means of a little light windmill turning on a fine wire axis, also by little wheels formed like water wheels, of the disposition and application of which wheels, and the various phenomena resulting I could, if I had time, tell you

a sheet." Today we have learned how to use this stupendous force whose harness is a wire and whose checkrein is a switch —a force that can drive trains, dredge a harbor, flood the night sky with light, cut a steel beam as if it were paper and warm the baby's milk. We can safely assume that electric power developed all over the country will finally make power service universal. It is therefore the duty of the electrical engineer to plan the system some time ahead, and not to allow it to grow without a general plan.

The tendency in the past was to construct power systems radiating from large central stations and to interconnect the lines of the different systems where they met. Such a procedure would not satisfy the needs of the future power industry with its large units and stations, its tremendous power resources and markets. The conclusion as to what course is best for the power industry is the same as that which is best for the country as a whole. It is evident that fuels, particularly oil, must be used for power only where hydro-electric power is not available as, e.g., in the propelling of air and ocean craft. The best course for the power industry, therefore, is the use of natural water power resources as far as is practicable for the purpose of conserving human energy and fuels. This will add to the stability of the power industry and bring about the development of water powers, which, transmitted to cities and industries, would operate in conjunction with large efficient steam power plants.

A comprehensive outline of interconnection of all the present existing power systems in the United States by means of 220 k.v. transmission lines was developed by F. G. Baum in 1923. It was the interconnected system of the Philadelphia Electric Co., the Pennsylvania Power & Light Co. and the Public Service Gas & Electric Co. of New Jersey which has made the first link in the scheme proposed by Baum. Yet the credit for the pioneering development of the 220 K.V. equipment must be given to the State of California.

It happens that the natural conditions in California are such as to have forced extensive water power developments and transmission. The location of sources of power being east of the large central valleys made it necessary to build transmission lines across and through the valleys in order

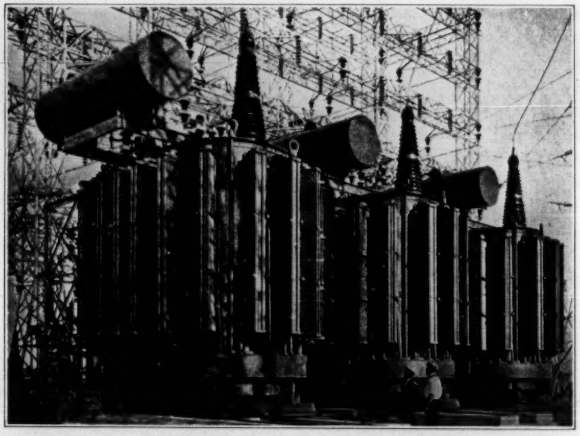
to reach the large industrial power markets and cities near the seacoast. The population on the Pacific coast is rapidly increasing, especially in the large cities, and their environs, and certain other districts where there is good land for food production, and irrigation is feasible. In respect to power supply, the Pacific coast states are fortunate because of the abundance of water power and of fuel oil for steam power. One authority states these water powers may have an ultimate development of 18,000,000 k.w. The supplied population is in the neighborhood of 5,000,000 and the electric power consumption per inhabitant is 0.25 k.w., the highest for the nation. Climate, topography and irrigable fertile soil are the great factors that determine the localities where people want to live. Rain or snow at high elevations determine the location of water powers. The result is that great distances occur between water power sources and markets. The increased transmission voltage greatly stimulated the development of water power in the mountains, the power being transmitted to cities and industries.

About 1908 transmission voltages of 100,000 were used and these have since been increased to 165,000 in the case of the Caribou-San Francisco line of the Great Western Power Co. In most of these installations the distance of transmission was not over 150 miles and amounts of power transmitted were limited to 25,000 k.w. per line. Because of the economic supply of fuel oil everywhere throughout the Pacific coast areas steam power stations can always be located at or near their corresponding markets, involving only short distance power transmission. Compared with steam power, unit hydroelectric power investment costs are high and operating maintenance and depreciation costs are low. The supply of hydroelectric power is subject to seasonal and annual fluctuation wholly without relation to demand. Steam power can supply demand at all times. A large part of the k.w. hours per annum required could therefore be furnished from water power, the balance being supplied more economically from steam power consumed as daily peak loads and to make up for water power deficiencies during periods of minimum stream flow.

The Southern California Edison Co. was the first to be

confronted with the problem of application of 220 k.v. Of the two alternatives, whether to build new transmission lines from their Big Creek System to Los Angeles or to change over the present 150 k.v. equipment to 220 k.v. the latter method was chosen as more economical. At the same time it was clearly understood that development of trunk transmission at 220 k.v. would involve new problems arising

Fig. 2.



Typical arrangement of the Great Western Power Company switching equipment.

from the high voltage, the large amount of power transmitted and the high service standards which the importance of the transmission would demand. An experimental line at 235 k.v. was equipped by the Southern California Edison Co. over a distance of seven miles proving the feasibility of successful operation. The new record 165 k.v. Caribou Line was then outdone by the greater feat of constructive imagination in changing the Southern California Edison Co. high lines to 220 k.v., shortly followed by the Pit River Line of the Pacific Gas & Electric Co.

It soon become evident that the existing power systems

should be interconnected to permit practically unlimited exchange of energy. A proposal to interconnect the California transmission systems through a great bus extending nearly the length of the State was outlined in a paper by R. W. Sorenson, H. H. Cox and G. E. Armstrong, read at the Pacific Coast Convention of the A. I. E. E. It proposed 1,100 miles 220 k.v. transmission bus of standard frequency, 60 cycles, in the belief that the Southern California Edison Co. Power System operating at 50 cycles would ultimately find it advantageous to conform to the A. I. E. E. standards. Such change has not been made as yet, instead frequency changing sets are being installed to permit the exchange of energy between the adjacent power systems. The calamity resulting from a drought in 1924 taught the "sunny South" a bitter lesson of the vital importance of interconnection. Two gigantic steam power plants and a large frequency changing station were built as a result of this memorable experience. Southern California recently had another opportunity to appreciate the value of interconnection when the failure of the St. Francis Dam occurred. The destruction of one of the power houses and failure of the transmission line put the entire power system of the Bureau of Power and Light in Los Angeles temporarily out of commission. The entire load was quickly assumed by the Southern California Edison Company whose system is now provided with an adequate steam reserve.

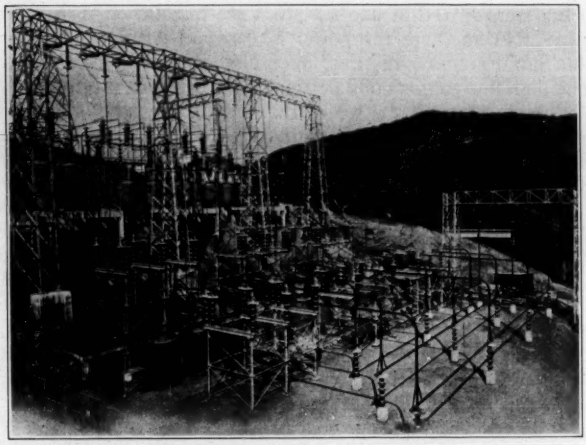
EQUIPMENT.

Factors which are practically negligible in the design of lower voltage switching equipment become of paramount importance in the design of stations for 220 k.v. operation. Perhaps no item in connection with electrical development of recent years has increased in greater proportion than the high voltage switching stations. All the existing 220 k.v. switching stations are of the outdoor type and there is very little probability in the future of a return to the indoor type arrangement. The space requirements for the switching of a double circuit line have increased from a few thousand square feet to more than a hundred thousand square feet. For example the Lighthipe Substation covers 30 acres, while Plymouth Meeting is laid over a tract of forty acres.

We shall now consider the existing 220 k.v. systems in the order of their installation.

The power system of the Southern California Edison Co. consists of a major group of hydroelectric plants, located in the Sierras, utilizing the waters of the Big Creek and San

Fig. 3.



Typical arrangement of the Southern California Edison Company Equipment.

Joaquin Rivers. The Big Creek power houses have been built to transmit power at 220 k.v. to Los Angeles—a distance of 250 miles. Two large receiving substations, Eagle Rock and Laguna Bell, terminating the two lines from Big Creek System, have been recently augmented by a third line and the additional Lighthipe Substation, tying the high lines with the general system and the newly constructed steam plant at Long Beach. There are two intermediate switching stations at Vestal and Magunden, located along the initial double circuit high lines, which are used for sectionalizing and cross connecting the lines. The Vestal Station also serves as a tie with adjacent utilities controlled by the same company. There is also a group of smaller

power stations located on the territory near the center of distribution. The frequency of the system is 50 cycles, 60 cycles being used on the subsidiary Mt. Whitney power system. The large blocks of power are distributed at 66 k.v.

The Pacific Gas & Electric Co. Power System consists of a major group of hydroelectric plants in the Sierras utilizing the waters of the Pit River and its tributaries, the power being transmitted at 220 k.v. to Vaca Substation, 150 miles away. From there the power is transmitted at 110 k.v. to the San Francisco district, an added distance of 60 miles. The high line consists of a double circuit without intermediate switching stations between Pit and Vaca, the standard frequency, 60 cycles, being employed throughout the system. A 110 k.v. tie is made with the adjacent power system of the California-Oregon Power Co.

The two large utilities in Central California—the Great Western Power Co. and the San Joaquin Light & Power Corporation are interconnected at present by means of 220 k.v. lines from Wilson Substation to Brighton, a distance of 105 miles. This connects the Feather River plants with the system of the San Joaquin Light & Power Corporation. These high lines operate at present at 165 k.v., 60 cycles being employed by both systems. This covers the 220 k.v. development in California up to the present time.

The Wallenpaupak project of the Pennsylvania Power & Light Co. employs 220 k.v. transmission from its recently built hydroelectric station to Siegfried Substation, 70 miles distant. This substation in turn is being tied with Plymouth Meeting, of the Philadelphia Electric Co., Roseland, of the Public Service Gas & Electric Co. of New Jersey, and the steam power plant at Sunbury, Pa.

The latest project employing 220 k.v. is the Conowingo plant, in Maryland, utilizing the water power of the Susquehanna River, this energy being transmitted to Plymouth Meeting by means of three high lines. This project was justified economically as the load of the Philadelphia Electric Co. System became sufficiently large to absorb nearly the entire output of the plant at all times. The interconnection between the Philadelphia Electric Co. and the two adjacent power systems belongs to the trunk line class of intercon-

nection as it is intended to facilitate the transfer of large amounts of energy.

The Plymouth Meeting Substation of the Philadelphia Electric Co. is located 65 miles from Conowingo, 49 miles from Siegfried and 77 miles from Roseland. Its 220 k.v. lines are employed for interconnection with the adjacent power systems, and 66 k.v. lines tying with the steam power plants in Philadelphia and vicinity. Standard frequency, 60 cycles is being used in the entire interconnected system.

Although extensive studies of design and operation of the existing 220 k.v. systems in the United States have been made by engineers of other countries this equipment has not been used commercially outside of the United States. However tentative projects are being considered in France and Russia.

From the foregoing it is evident that each of the companies employing 220 k.v. had to meet different conditions and cope with new problems continually. A close study of the individual systems reveals that the engineering staff of the Pacific Gas & Electric Co. displayed originality and radical ways of solving all new problems. Other companies followed the established routine and methods used on their low voltage equipment, with the exception of the Philadelphia Electric Co. The latter, benefiting by the experiences and unavoidable mistakes of other systems, ventured the introduction of many new features.

A glance at the map shows that the distances of transmission circuits employed in California are above 100 and below 300 miles, while in the Eastern group of lines the distance between large power centers ranges from 50 to 100 miles.

The bus is supported either on a steel structure, latticed steel poles or concrete posts. Insulator posts composed of a single or double stack of pillar insulators have been used recently, quadrupedal insulator supports having been used only on the earlier installations. Four inch copper tubing or iron pipe is being used on the double bus installations, the double bus system predominating. Branch bus bars are welded or clamped to the main bus and stiffened at the point of attachment by knee braces on each side of the branch.

Provision for expansion is made on all long bus spans, flexible connection being frequently employed for current carrying purposes. The single bus is used on the Pacific Gas & Electric Co. system, employing by-pass switches which enable continuous operation when the circuit breaker is disconnected for repairs or inspection.

Aluminum cable with steel core is used for line conductors as the most suitable type of conductor considering long spans and corona losses. Two circuits per line are commonly used although three circuits have been recently employed.

A great variety in types of transmission towers used is due to different topographic and climatic conditions of the territory. The single circuit towers with horizontally spaced conductors prevail, while double circuit towers are used in the valleys. A radical departure from the general practice is made by the Pennsylvania Power & Light Co. which employs guyed mast type of structure at angles and dead end points of the line where overturning loads on the towers must be carried constantly. This type of tower has been frequently used with success on the European installations but it may present difficulties in case of the necessity of using a ground wire on the line. The power is interrupted and synchronizing is carried out on the high tension side.

The disconnecting switches are the determining element in the design of the outdoor structure. It may be safely said that there are as many types of switches employed as there are 220 k.v. stations in operation and new types are being developed continually. Gang operated switches are used almost exclusively with manual or motor mechanism, the cantilever, carriage, tilting insulators and rotating insulator type switches with or without grounding attachment being installed on the existing systems.

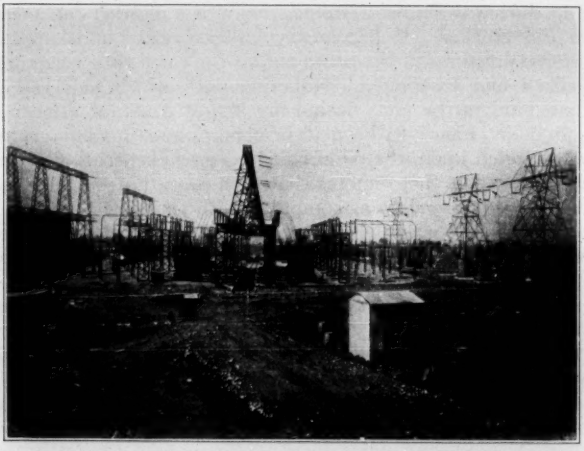
In a 220 k.v. power system where a very great amount of energy is transferred any change of current conditions requiring a sudden change of energy is liable to be destructive. One is easily convinced of the truth of this when one observes the results of a short circuit on a high line or a blow-up of an oil circuit breaker. The requirements of correct system operation demand oil circuit breakers that will not only clear the fault successfully but accomplish this safely in a minimum of

time. Operating experience over the last five years has definitely shown that if trouble is cleared within a certain minimum time little if any burning will result. The rating of the 220 k.v. oil circuit breakers used on one of the latest installations was 2,500,000 k.v.a. interrupting capacity. Direct current is generally used for the operation of breakers. In its present form, the oil circuit breaker is by far the weakest link in the high tension transmission system. Mineral oils with a relatively high flash point are the generally used insulating medium of the present breakers. It must be noted however that during the time of arcing, the oil is a decided detriment to the breaker. It becomes volatilized and builds up excessive pressures in the container, at the same time becoming ionized and forming a conducting path which aids rather than hinders the arc. Requiring almost constant attention and maintenance to keep it in condition to render service when called upon, the oil circuit breaker fails occasionally in its duty. The fact remains that with everything in its favor the service it renders as compared with that given by other classes of equipment is not nearly proportionate to its cost and the care required in its selection and subsequent upkeep. An interesting current interrupting device in the form of the vacuum switch, under experiment at the California Institute of Technology, has appeared recently. While development has not yet reached the point of commercial application the prospects seem encouraging.

The development of transformers indicates a tendency towards larger sizes and more complicated design. Single phase Y connected units with solidly grounded neutrals on the high side are generally used. The early capacity of 50,000 k.v.a. per bank has now reached 130,000 k.v.a. largely due to the application of air jet radiator cooling. Self cooled, water cooled and a combination of self and forced air cooling have been used on the existing installations. Three winding type transformers are employed most frequently. The tertiary winding, being delta connected, provides a path for the third harmonic present in the voltage wave, thus avoiding high insulation stress. Tertiary and quarternary delta connected windings are sometimes used for synchronous condenser starting and operating, also to absorb

the triple frequency exciting current. The use of low voltage taps on the transformer windings for starting the condenser is not so popular since it results in a higher ratio of the bank during starting than that obtained while the condenser is running. This upsets the balance between the current transformers used on the high and low side of the bank for differential protection. The latest installations employ equipment with tap changing under load. The use of transformers with variable ratio

Fig. 4.



Plymouth meeting. General view of substation looking southwest.

introduces a flexibility in operation which permits the division of wattless currents between stations independent of voltage held at the generator busses. Single phase auto transformers rated 36,700 k.v.a. each have been used on the early installation of the Southern California Edison Co. when a change was made from 150 to 220 k.v. operation. An interesting feature is that these auto transformers are tied in solid with the transmission lines and form an integral part of it. They are the largest auto transformers in existence.

Bushing type current transformers are used on the oil

circuit breakers and power transformers. No other type of metering transformers has been used so far except on the latest installation at Plymouth Meeting where the Conowingo lines are equipped with high voltage potential transformers and the lines connecting with the adjacent systems are equipped with 220 k.v. metering equipment.

On long distance transmission of large amounts of power stability is the controlling feature. Synchronous condensers are generally used at the end of transmission lines for stabilizing voltage and affording power factor correction. On long lines at high voltages the charging current at no load, being a leading quadrature current, causes a voltage rise over the line when flowing over the reactances found in its circuit. At heavy loads the power current causes a voltage drop flowing over resistances and reactances in the circuit. Thus by introducing at no load a lagging quadrature current, voltage rises may be compensated for, and by introducing at a heavy load a leading quadrature current, voltage drops may be compensated for. Synchronous condensers therefore are valuable in increasing the power capacity of transmission lines, adding to stability, and allowing a simplified method of voltage regulation by the system operator. The size of condensers recently installed is 50,000 k.v.a. as compared with the 20,000 k.v.a. of the early type. A new method called quick response excitation has been employed in the recent installations. It requires an auxiliary exciter for the field of the main exciter, the latter being therefore a separately excited machine. A new regulator, unique in its operating characteristics, has been developed which makes it possible to sustain stable operation under condition of dynamic stability, thus increasing the maximum power by taking advantage of a heretofore unexploited range of operation of synchronous machines. The object of a quick response excitation system is to build up rapidly a voltage across the field winding of a synchronous machine, to provide sufficient additional magneto-motive force to neutralize the demagnetizing action of the short circuit current flowing in the armature winding.

Protective relays on any extensive transmission system play fully as important a part in the rendering of continuous

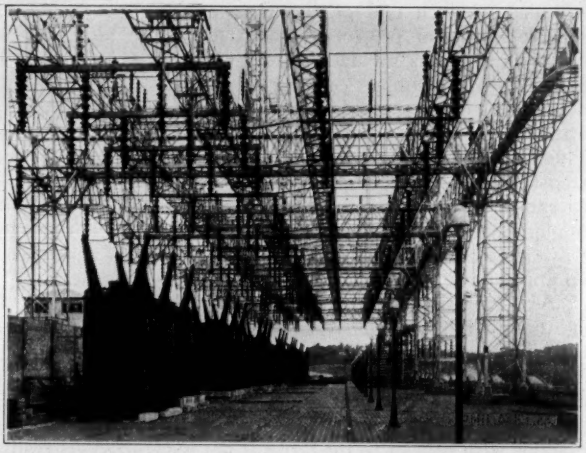
satisfactory service as any other class of apparatus on the system. Being automatic and selective they are infinitely quicker and more accurate than the average good operator, requiring little attention on his part. The interconnection of large power systems requires special treatment of its protective relay installation in order to secure proper automatic sectionalizing. It must be such that the power loads supplied to the line or taken from the line may vary, that the flow of power over sections may be actually reversed without disturbing the voltage regulation necessary to give good service at all points. Interconnection therefore between large power units imposes more strenuous demands on the relay protective equipment than do individual systems, even those of a large size. The most important requirement is that all the faults be cleared quickly, thus preventing unnecessary burning of conductors and equipment and minimizing the possibility of the system becoming unstable. It must allow flexibility of system operation and perfect protection when any line or piece of equipment is cut out of service, without change in relay adjustment when a large unit of power is entirely removed.

A great variety of protective schemes has been used on the existing 220 k.v. systems. The balanced relay protection, with an automatic arc suppressor cutting in resistances in the field of generators and condensers, operated by the neutral ground relays, has been used by the Southern California Edison Co. The prevailing scheme on the other systems is the one employing directional power overload and directional residual relays. Impedance relays are being used on the latest installations and a novel system of transmission line protection by means of carrier current pilot system has been experimented with recently. A comprehensive view of the matter produces the impression that the entire problem of relay protection of the 220 k.v. interconnected systems is still awaiting solution.

The problem of lightning protection is perhaps as old as our knowledge of electricity itself. Benjamin Franklin writes of "thunder gusts and sudden storms of thunder and lightning which are frequently of short duration but sometimes produce mischievous effects." He conducted numerous

experiments in which his life was endangered, trying to investigate the nature of the phenomena and to find means of protection against them. This problem is still a matter of continuous investigation in Europe and in the United States and the development of the Cathode ray oscillograph, clydonograph and the high speed photographic camera have greatly assisted in clarifying certain problems pertaining to the nature of lightning. These "mischievous effects" prove

Fig. 5.



Conowingo Station—General view of 220 kv substation. Elevation 121.6'. Looking northeast.

to be a matter of serious consideration where transmission lines and outdoor substations are subject to frequent and severe lightning. The investigation of lightning surges indicates that the highest of lightning voltages exceeds the strength of any insulation in use at this time. If it were possible to by-pass the lightning voltage surge to ground without the power arc following the by-pass, we would have a very satisfactory method of getting rid of the surge. In the case of line and switch gear insulation some reasonable dependence on the upper limit of insulation strength may

be considered. Insulation within such apparatus as transformers, however, is quite different. Failure in this case usually occurs by puncture. It is quite conceivable that a transient voltage not high enough and not long enough to cause failure would cause a partial failure and if repeated may cause a partial puncture followed by destruction of the insulation. It appears therefore to be a matter of paramount importance to protect properly the apparatus in the substation. Previous experience has indicated that different types of lightning arresters in connection with choke coils installed at each end of the transmission line provide a reliable means of protection and relief. The high cost of lightning arresters for 220 k.v. lines caused serious investigation into the subject of their effectiveness. As a result, none of the existing 220 k.v. systems has employed lightning arresters except the latest installations at Conowingo and Plymouth Meeting. On account of the great extent of the transmission line as compared to the station, it is reasonable to expect that a very large share of the disturbances will originate on the line and can reach the station only by traveling along the line. The line insulation thus constitutes an upper limit for voltages which may reach the station.

As a rule the lower the line the less its susceptibility to lightning. For obvious reasons, a 220 k.v. line cannot be brought very close to earth, therefore some method of bringing an artificial earth close to the wires may prove effective in providing lightning protection. Ground wire has therefore been installed on most of the existing k.v. lines. The practice with respect to the latter is not recognized generally. Some of the companies employ no ground wires while others use as many as two ground wires per circuit. The matter of lightning therefore offers a rich field for further practical investigation and scientific research.

INSULATION.

Since a very large amount of power can be transmitted at 220 k.v. over long distances it is questionable whether higher voltages will be required for a national transmission system. The insulation, as the most vulnerable element of the high voltage development, is a matter of the greatest importance,

its deterioration being the most rapid. It may be said that the length of life of a high voltage system is that of its insulation. Our knowledge of the behavior of insulating materials under variation of voltage, frequency, temperature, humidity and mechanical stresses is very meager, hence insulation in its present form is the least susceptible to exact computation and design. The present methods of control of the important properties of insulating materials, singly and in combination, are very imperfectly developed. As a consequence when designing insulation for 220 k.v. equipment more than liberal provisions are made against these uncertainties, allowing large factors of safety and thus resulting in large sizes and high cost of equipment. Matter in all physical states must be considered in discussing material used for installation —solid insulation such as porcelain and fibrous compounds, liquid insulation such as oil, and gaseous such as air. The latter always appears in connection with solids and therefore plays a vital rôle in the problem of insulation.

The dielectric properties of air were already known in the earlier stage of electrical science. Benjamin Franklin, speaking of the air, says "It assists in confining the electrical atmosphere to the body it surrounds and prevents its dissipating. Air is an electric per se and when dry will not conduct the electrical fire" (meaning electricity). We have discovered since that the effect of placing any insulating body into the static field which exists between two conductors, as represented by a transmission line wire or bus and grounded insulator bracket, is to increase the stress in the air path at the surface of the conductor and the surface of the insulating body. Certain phenomena which were unnoticed because of their feeble effect when low voltage insulation was considered, with the application of 220 k.v. caused a greater energy density, becoming therefore a controling feature. Conductor sizes of a transmission line, calculated according to the previous methods, produced the so-called corona effect resulting in loss of electric energy. It soon became evident that it is much more important to design the dielectric circuit for proper flux distribution than the magnetic circuit, since local overflux density in the magnetic circuit may only cause losses, while in the case of

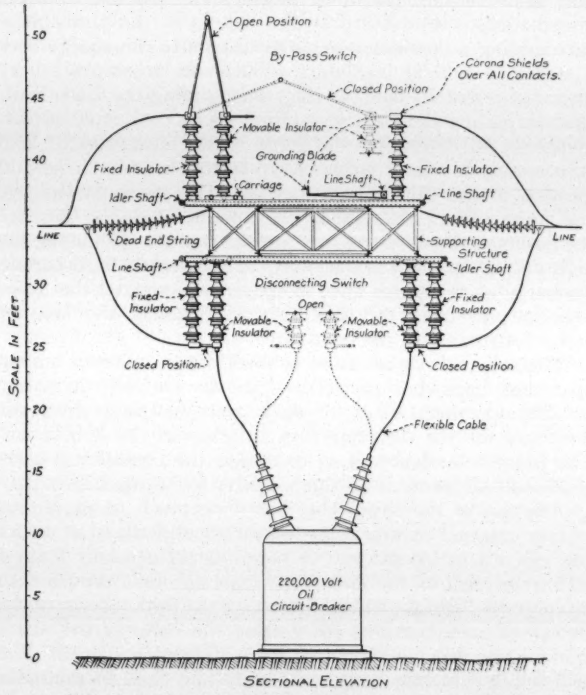
the dielectric circuit it would cause a rupture of insulation or flashover.

The most important form of solid insulators employed on 220 k.v. equipment are the bushings used to bring out the lead terminals of the transformers and oil circuit breakers. Two kinds of bushings are commonly used—the oil filled and the condenser types. In the design of oil filled bushings two problems present themselves: The internal stress on the oil which determines the puncture voltage, and the external stress on the air which determines the arc-over voltage. The condenser type bushing is built with the object of stressing all of the solid insulating material approximately equally, which may be accomplished by means of a number of cylindrical concentric condensers of equal thickness but unequal lengths.

Whereas the design of the station apparatus insulation did not present appreciable difficulties the problem of line insulation required a great deal of research and experimentation. It soon became clear that a statement of volts and number of units in a string does not determine the stress on an individual unit. The general understanding is that the stress on the insulation does not depend altogether upon the voltage but also upon the configuration or the shape of the electrodes, for example: with needle points the flux density at the point is very great at a fairly low voltage, while for large spheres a very high voltage is required to produce high flux density. Every insulator in a string may be considered as a condenser and a string can generally be thought of as consisting of a number of separate condensers in series, the dielectric being alternately air and porcelain. The fact that the ratio of the mutual capacity of the units to the capacity between the suspension link and ground is an important factor in determining the distribution of potential over an insulator string, suggested the importance not only of the shape and surface area of the metal fixtures on the individual insulators, but also the length of the connecting link or spacing between the insulators. Laboratory tests using potentiometers have shown that where the mutual capacity is small in relation to the ground capacity there soon comes a point beyond which it is useless to put more insulators in the string. The problem

therefore was to secure a more or less evenly distributed potential gradient. In order to correct this gradient and make it a uniform slope more nearly approaching the ideal straight line several methods have been employed to adjust

Fig. 6.



Sectional elevation of the Pacific Gas and Electric Company switching equipment.

the capacity. The use of insulators of varying capacity in the string was found to be a good solution but it had obvious disadvantages from a line maintenance point of view. It has nevertheless been employed on the high lines of the Pacific Gas & Electric Co.

Investigations conducted by Prof. Harris J. Ryan and his associates in the high voltage laboratory of Leland Stanford University, Cal., have shown that the distribution of potential across the insulator units becomes less uniform at higher voltages, the gradient being extremely high on the unit near the line. However it was found possible to direct and modulate the critical strains set up in the atmosphere surrounding a conductor so as to distribute the charge over a string of several insulators. This was accomplished by means of a metal shield, or ring, surrounding the lower unit, thus increasing the capacity. Prof. Ryan conducted experiments so to determine the form of the electrostatic field surrounding insulator strings as to relate the size, shape and location of the shields in a way that the stress on the live end units will be decreased, yet not unreasonably decrease the flashover distance to tower and crossarms. Reducing the high voltage across the line unit, he eliminated local corona discharge at this point and, moreover, encouraged the flashover to pass from the shield ring to ground, the arc not being destructive to the insulators.

Regarding the application of shield rings, opinions among operating engineers are still divided. On all the early installations shield rings, or discs, were installed along the lines and on the disconnecting switches in the substation. The present tendency is so to design the conducting parts and hardware as to avoid the necessity for using shields.

The use of the shield ring has done much to show that certain external modifications may radically alter the duties and efficacy of insulators. A metal shield carefully shaped and connected to one end of an insulator unit provides an equipotential surface which distributes the field. Some of the European manufacturers recognizing the value of the metal shield have developed a new type of insulator made of a cylindrical porcelain body, with only one shed to minimize leakage, and a metal cap cemented at each end, the one at the top being provided with a wide copper shield. A step further in this direction was taken by Prof. Harold B. Smith, of the Worcester Polytechnic Institute. His design not only provides for proper distribution but furthermore places the actual dielectric in the zone of minimum density. Electrical

breakdown therefore occurs not in the insulating element but somewhere in the surrounding field, thus the heating and ionization of the dielectric, which are generally supposed to precede the breakdown, are obviated. The effectiveness of this insulator was demonstrated at the A. I. E. E. Convention held in Pasadena, in 1924, at the inauguration of the new 1,000,000 volt laboratory of the California Institute of Technology. It took almost 1,000,000 volts to arc over two of the insulators in series.

In reviewing the problem of 220 k.v. development, consideration so far has been given to the design of equipment and apparatus. Now it remains to consider the operation of the existing systems. The experience of commercial application of 220 k.v. dates from the latter part of 1923, and, notwithstanding its imperfections, the system has given comparatively little trouble. The greatest difficulty outside of purely incidental cases is caused by faulty relay operation and the flashovers, the latter presenting the greatest source of trouble and frequently perplexing the operating engineers. There is still the necessity of exercising great vigilance and careful investigation of lines while operating under conditions of heavy switching and during atmospheric discharges. In the early stage of the development it was assumed that the line should be designed so as to operate at nearly critical corona voltage, any disturbance, therefore, resulting in a higher voltage would quickly expend its energy in producing corona loss. This in turn would permit a smaller safety factor to be used on the insulation.

A detailed investigation of corona loss was made by Peek and expressed in his well-known quadratic law. Accurate power measurements of corona loss on a high tension line are difficult to make because of the nature of the phenomena and the circuit itself. Measurements on the low side of transformation could not be relied upon due to the difficulty of separating the different losses. Recent measurements with cathode-ray oscillograph have shown that the loss follows the quadratic law only above the visual critical voltage. Peek's formula, therefore, was found to be close enough for established corona conditions, whereas in actual practice on high voltage lines under normal atmospheric conditions the con-

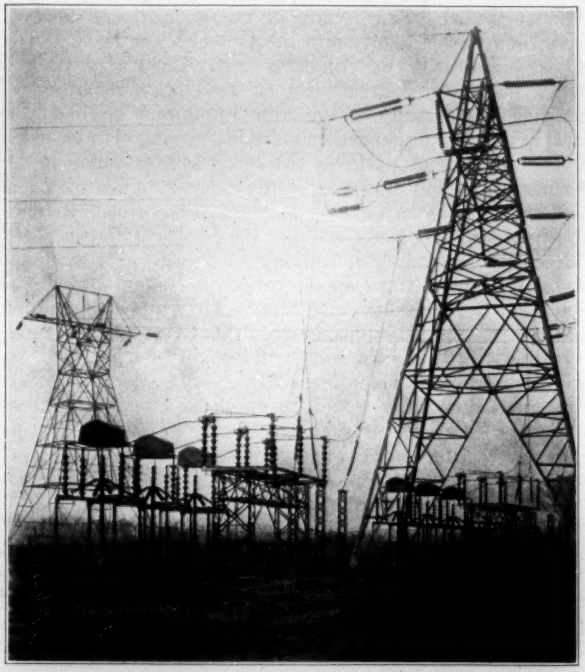
ductors show no visible corona, and when the nature of the phenomenon becomes unstable the loss is extremely difficult for exact calculation. It appears that the most dependable method of accounting for corona losses would have to be based upon actual measurements on the high voltage side.

Considering the possible future development of a national interconnection it may be worth while to mention the possibility of 220 k.v. underground transmission. It is well understood that overhead circuits are exposed to a great extent to the influence of the weather, particularly storms and rain. There always adheres the disadvantage of an open air circuit being subject to all influences including intentional malicious interference. Another drawback is the impossibility of bringing the overhead 220 k.v. lines directly into the city. For these reasons the future development of 220 k.v. interconnection may be in the direction of underground cables. An important factor to such decision may be eventually the rapid development of aviation, to which high voltage lines represent great danger, and there will be hardly any means in the event of sudden fog to render the existence of overhead lines noticeable to the flyer. At the same time it is well understood that maintenance of cable network and supervising service is much smaller than with an exposed overhead line, the life of the cable being correspondingly longer.

The insulation of high voltage cables is always of limited thickness and therefore subject to a high dielectric stress. Dielectric losses are known to cause internal heat which raises the temperature. This in turn limits the current capacity and produces local heat spots and deterioration of the dielectric material leading ultimately to failure. At present, efforts are being made to deal in a scientific manner with the subject in which the past development has been so far largely experimental and "cut and try methods." The general problem of insulation is emphatically one in which scientific treatment is to be sought for. At the same time it is necessary to urge the utmost caution in interpreting the dictates of new theories. Care needs to be exercised not only in connection with the more complicated problems of insulation but danger exists in making errors in the interpretation of the fundamental laws which effect the result in the most simple cases.

Even the simplest natural phenomena leave us groping when we seek their ultimate understanding as a sequence of cause and effect. In our effort to understand the nature of each cause we soon reach the limit of our exact knowledge and

Fig. 7.



Plymouth Meeting. General view of 22003–22010 kv Westinghouse lightning arresters.

are led into the realm of metaphysical speculation. For the most part, in the field of dielectric phenomena, we would be content if we could express them in terms of the fundamental relations of mass, motion and energy which are the foundation stones for erecting the structures of theories accounting for

more complex natural phenomena. The word theory is therefore only a relative term, meaning that we can explain a newly observed phenomenon in terms of a more fundamental phenomenon whose laws are well recognized. Since the earliest discovery of the property of dielectrics many hypotheses and explanations of their origin and nature have been suggested. Few if any of the suggestions, however, have risen to the dignity of a theory which can be supported by a quantitative experimental test. Electricity itself is still a matter of a great deal of speculation regarding its meaning and nature. Benjamin Franklin's original conception of it is thus defined in one of his letters, "The electrical matter consists of particles extremely subtle, since it can permeate common matter even the densest metals with such ease and freedom as not to receive any perceptible resistance. If any one should doubt whether the electrical matter passes through the substance of bodies or only over and along their surfaces a shock from an electrified jar taken through his body will probably convince him." How admirably simple and, at the same time, instructive to those engaged in studies pertaining to the ultimate structure of matter with the powerful aid of mathematical science. Of course the modern transmission engineer would be ess prone to apply methods suggested by Franklin, when attempting to convince anyone about the existence of electricity, because the mere approach to a 220 k.v. transmission line at any distance less than four feet is positively sufficient to relieve any living creature of all his earthly cares.

Benjamin Franklin was the first to show the importance of the dielectric medium when he described the properties of a Leyden jar. Faraday's great contributions to the study of dielectric properties of material were his ideas of lines of force, tubes of induction, dielectric polarization his emphasis of the importance of the medium in the phenomenon of electrostatic induction, his measurements on different dielectrics, and his discovery of the fundamental property, spec fic inductive capacity. But it was the genius of Maxwell that built the theory of potential as applied to the electric field and to dielectric behavior, which still constitutes the starting point of any discussion of dielectric phenomena. Yet the

classical theory developed by Faraday and Maxwell assumes that dielectrics have only one property—the specific inductive capacity. It tells us nothing of dielectric strength, of phase difference under alternating stress, and very little of the conductivity of dielectrics. While the relative importance of these properties may vary as amongst different types of service, all of them are involved in high voltage alternating current service. The classical theory is utterly insufficient to guide us in our efforts to understand and control the important properties of insulation as utilized in high voltage equipment. Extensive research conducted during the last twenty-five years was instrumental in the discovery of certain properties not accounted for in the theory of perfect dielectrics. It was soon recognized that these special properties are perhaps the most important of all, owing to the limitations they impose on the performance of high voltage insulation. The most important of these properties are the dielectric absorption and the dielectric loss.

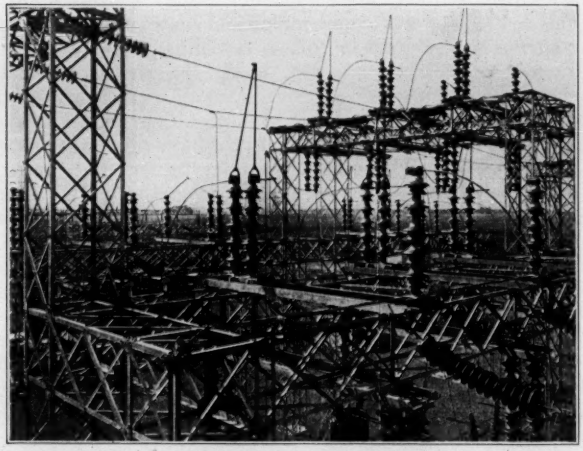
From the standpoint of engineering practice the dielectric absorption is considered as a conduction phenomenon and therefore, in all cases of alternating stress, occasions a component of current in phase with the applied voltage. This means an energy loss in the dielectric, causing heating and danger to the insulation. The situation is aggravated by the fact that in high voltage equipment composite insulation is used which usually possesses high absorption. The fundamental loss of even the purest and simplest of dielectrics is not clearly defined. While the explanation of dielectric loss is obvious, it is not yet possible to formulate definite laws connecting the losses in dielectrics with the simpler and more fundamental properties of the materials themselves.

Of all existing theories which propose to account for these special properties no single one of them is entirely satisfactory. Many of them are obviously imaginary structures erected in the effort to picture some artificial mechanism conforming to the known experimental facts. Others are merely ingenious sequences of mathematical manipulations.

CONCLUSIONS.

Summarizing the entire field of 220 k.v. development and its present status certain general conclusions may be drawn. It is evident that the development leaves much room for improvement in general methods, apparatus and installation. The critical eye is impressed when observing the mass of steel,

Fig. 8.



Typical arrangement of the Pacific Gas and Electric Company.

copper, oil and particularly the porcelain and hardware of the insulation used to commutate electric current, that there is something wrong with the present way of attacking the problem. What may be termed "brute force" characterizes the proportioning and methods of using the material. There seems to prevail a strong adherence to the old practice while neglecting the quest for new ways. Many things have been actually applied where far greater care should have been exercised in their choice. Nevertheless we often hear undue praises which call for sounding the alarm of caution. Perhaps it might be worth while to quote the concluding paragraph of Franklin's letter to an English scientist in which, after a long

description and explanation of strikingly original new experiments with electricity, he writes, "These thoughts, my dear friend, are many of them crude and hasty, and if I were merely ambitious of acquiring some reputation in philosophy I ought to keep them by me till corrected and improved by time and further experience." This thought occurred to me when looking at the first steps of our practical application of 220 k.v. equipment. A study of these first installations would prove of great interest and value to every power engineer, for by intelligent analysis he could learn at least one important thing and that is—how not to design 220 k.v. equipment.

The problem of insulation should perhaps be approached from a new angle. It can no longer be viewed as one of interposing a certain thickness of insulation or a greater number of cap and pin units between the line and ground. A thorough knowledge and understanding of the material used and its properties is of the greatest importance. The engineer, therefore, can no longer content himself with the former rules of engineering practice, for the equipment and devices which he has come to use draw more and more upon the properties of fundamental and fine grained structure of nature, the elucidation of which is the problem of modern science. In the meantime, however, it is necessary to use available equipment and to improve the methods of use rather than to await developments which may some day offer the solution devoutly desired. Further experimental and theoretical research is of vital importance to lessen the confusion and uncertainty of our new power developments, and it would be wise to recall what Franklin said of research, "Frequently in a variety of experiments though we miss what we expected to find yet something valuable turns out, something surprising and instructing, though unthought of." That something can be expected only when research keeps in step with actual field and operating experience, and every inducement should be offered to open minded engineers for developing a greater theoretical knowledge of the art.

Evidence of the Presence of Protons in Metals. ALFRED COEHN. (*Naturwissenschaften*, March 16, 1928.) A quantitative study of the solution of hydrogen in palladium, iron and other metals indicates that it exists there in atomic form. If this be the case, it would seem likely that some of the hydrogen atoms would liberate electrons as the metal atoms are supposed to do. In the metal there should then be electrons derived from both hydrogen and metal atoms, neutral metal atoms, metal atoms rendered positive by the loss of negative electrons, neutral hydrogen atoms and protons, that is, positively charged hydrogen nuclei resulting from the removal of the electron from a hydrogen atom. The atoms of metal are fixed in position on the crystal framework but the hydrogen can move and does move as is shown by experiments on its diffusion through metal foil.

Protons have a positive charge. Can their motion in metals be affected by the application of an electric field? To answer this the following experiment was tried. The middle centimeter of a palladium wire 6 cm. long was twisted together. This part of the wire dipped into dilute sulphuric acid, extended vertically upward and was prolonged horizontally to right and left by the remainder of the wire. Each horizontal part of the wire had V-shaped bends in it for testing potential by contact with dilute acid. By making the twisted part the cathode hydrogen was supplied to it. This diffuses impartially toward both ends of the wire. Let the wire now be traversed by a second current, independent of the electrolyzing current and much stronger than it. Under these conditions the hydrogen travelled faster toward the cathode end of the wire. Its presence was detected by the difference of potential set up. After the second current had flowed for 55 or 60 hours two corresponding places to right and left of the twisted wire showed a difference of potential of .1 to .15 volt. Reversing the current caused a reversal of the potential difference between the two points. It was thus possible to drive the hydrogen back and forth in the palladium wire. The conclusion is that protons are present in the wire. G. F. S.

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

SPELLER'S METHOD OF MAKING AND FINISHING WELDED PIPE.

HALL OF THE INSTITUTE,
PHILADELPHIA, November 2, 1927.

No. 2873.

THE Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating Doctor Frank N. Speller's Method of Making and Finishing Welded Pipe, reports as follows:

The purpose of this invention is the mechanical removal of the thick oxide scale that is found on the surface of pipes that are made by the welding process. The removal of this scale cleans the surfaces of the pipes, making it possible to apply a more uniform coating of zinc, or other protective materials, for the prevention of corrosion.

The invention is protected by a number of United States patents, the earliest application having been filed on February 8, 1913, for a "Method of Finishing Welded Pipes," on which patent Number 1,171,757 was granted on February 15, 1916, to Frank N. Speller, of Pittsburgh, Pennsylvania.

The method of removing scale in the prior art was by the use of an acid pickling bath. The objection to this method is that since the thickness of scale on the inside of the pipe varies and averages greater than that on the outside, either patches of scale are left on the inside or the outside is over pickled, or burned.

In the process under investigation the scale is removed while the pipe is at a forging heat, but at such a temperature that while passing through the rolls, the scale will crack and separate from the metal.

A flat piece of skelp from which pipe is to be made, is heated in a welding furnace. Leaving the furnace, it goes onto a draw bench on which it is welded into a pipe by the butt weld process. It then is passed through sets of rolls

by which it is reduced in diameter and made truly cylindrical while its temperature is slightly below that of welding. The pipes are then carried sidewise across a transfer table at such a rate that they cool to a temperature slightly below that at which the scale sets. On leaving this table they are passed lengthwise through sets of rolls by which they are first changed in cross section to an oval shape and then back again into a circle. In this process the mean diameter is reduced and the length increased.

In this operation the scale on both the outside and inside is cracked off and removed while the temperature of the pipes is sufficiently high to prevent injury to the metal.

This process has been in extensive use since 1913 by the National Tube Company and for a shorter time by other companies. This pipe is in use as conduit for electric wires. and has been investigated and approved by the Underwriters for that purpose. It is also extensively used for water, gas and steam conduits.

The smooth interior of welded pipes that are scale free, provides a channel for water, that has little friction and secures a full delivery since there is no obstruction to the flow. The difficulty of clogged valves due to loose scale does not occur with a scale free pipe and there is much less pitting of the pipe.

The thick scale left in the inside of pipes by the ordinary methods of manufacture is the cause of most of this pitting which is the result of an electrolytic process since the scale is negative to the metal and under certain conditions a thermo-electric couple is set up. The removal of the scale prevents such action and leaves a smooth uniform interior surface.

Seven claims are allowed in Patent No. 1,171, 757. The first refers to the method of finishing welded pipes which consists in altering the cross sectional contour of the welded pipe while heated to a temperature at which the scale sets.

Claim seven describes the method in detail as follows:

> "The method of finishing welded pipes which consists in welding the pipe skelp, cooling the welded pipe to a temperature below that at which the scale sets, and then distorting and restoring the cross sectional contour of the pipe to thereby loosen

and remove scale from the surfaces of the pipe and elongating the pipe in the distorting and restoring operations."

Replies received to letters of inquiry to users have been very favorable concerning the practical use of this pipe.

In consideration of his invention of a method of manufacturing scale free pipe and its successful application, THE FRANKLIN INSTITUTE awards its EDWARD LONGSTRETH MEDAL to DOCTOR FRANK N. SPELLER, of Pittsburgh, Pennsylvania.

THE WORK OF HENRY FORD.

HALL OF THE INSTITUTE,
PHILADELPHIA, March 7, 1928.

No. 2878.

The Franklin Institute of the State of Pennsylvania acting through its Committee on Science and the Arts, investigating the Work of Henry Ford, of Detroit, Michigan, reports as follows:

Henry Ford, the son of William and May Litogot Ford, was born on July 30, 1863, at Greenfield, near Detroit, Michigan. His early life was spent on his father's farm and his education was received at the district school in Greenfield. Living the life of a farmer's boy he became acquainted, in a practical way, with the work to be done on a farm, and later used this knowledge to good advantage in devising machines that have proved of great value in farming operations.

The long and toilsome days of the busy season on the farm did not appeal favorably to young Ford, and since he was interested in all kinds of machinery, he became an apprentice in an engine works where he learned the machinist's trade. Becoming an expert machinist he made rapid progress, and was advanced from one position to another until he became the chief engineer of the Detroit Edison Company.

Mr. Ford made many inventions, and took out many letters patent, in foreign countries as well as in the United States. The first in the United States, No. 686,046, was issued on November 5, 1901, for a Motor Carriage, and was assigned to the Detroit Automobile Company. Many patents

followed in later years, covering many parts of an automobile, and accessories, such as mufflers, chain adjustments, drive gears, steering mechanisms and speed controllers. Perhaps of all Mr. Ford's inventions, that of the planetary drive gear (U. S. Patent No. 787,908, of April 25, 1905) was most significant; for that gear was used on the famous Ford car known as the Model T. These patents of course covered the four cylinder car, known as Model N, of which there were sold in two years a number of cars in excess of the total number of automobiles which all the motor car makers of the world together had been able to produce previously.

The first car was completed in 1892 when Mr. Ford was twenty-nine, but the increase in production was slow for the first few years, it being ten years before the first thousand machines were built. The Ford Motor Company was formed, though, with a small amount of paid in capital, about $28,000, and its progress was necessarily slow. During the early years of automobile production, development was delayed in many cases on account of the Selden patents which were so broad that they covered almost any kind of motor applied to a four wheeled vehicle. Manufacturers were compelled to pay royalties on this patent for some years until after a long series of legal trials the matter was finally settled by a decision in the United States Court of Appeals, in the case of Selden vs. Ford, et al., which declared that the statement "that Selden has solved a great problem and is entitled to the status of a pioneer inventor, is, we think, without foundation."

In all of this litigation Mr. Ford was a leading figure.

In the meantime automobiles were being built abroad by Daimler and Bentz, and in this country by Duryea, Ford, Olds and others and the defeat of the claims of the Selden patent gave such an impetus to automobile construction that the number in use rapidly increased.

The manufacture of machine Model "N" was discontinued and the Ford Machine, Model "T," was standardized in 1908, both as to type of machine and method of manufacture. The output of the Ford automobile manufactory increased from about 10,000 in 1908 to 2,000,000 in 1923 with a falling off during the years of the World War.

The reduction in cost of the Ford car to less than one-

third of the original cost is due to a combination of the following causes: the making of a standard car with parts that are interchangeable; standardization of the manufacture of it; the introduction of moving conveyers by which the work is brought to the workman, each man doing one operation at which he becomes expert, and a determination on the part of Mr. Ford to furnish these cars at prices low enough to permit of their widespread use.

The conveyer system employed in the Ford plants has been an important factor in securing a high rate of production. In this system a continuously moving platform is loaded at the proper intervals with the parts to be used by the workman who stands in one place and makes use of the part as it is brought to him. A careful test is made of the time of each operation and the rate of the moving conveyer regulated accordingly.

The practical result of the introduction of this system has been to increase greatly the speed of manufacture and to facilitate mass production. The last operation in the succession is the assembling of the automobile, which is done on a long moving platform or track, on which the different parts are added in order. When the end of the track is reached, the car can be driven off under its own power.

The conveyer system applied to the assembling of cars, introduced by the Ford Motor Company, and which has been revolutionary in its effect, is now in general use by the automobile and other industries where mass production is required.

On May 26, 1927, the 15,000,000th Ford automobile left the platform driven by Edsel Ford, President of the Company, with his father as passenger. Going to the Museum of the Company, Ford Machine No. 1 was brought out and driven by Henry Ford.

The tremendous increase in the output of the Ford Motor Company is seen in the fact that it operates thirty-five branches in the United States of which thirty-two are assembly plants.

The increased manufacture called for a great amount of raw material and for its preliminary manufacture into the various parts used in an automobile. Believing that these

parts could be manufactured for a lower price by his own plants than that paid for them in the markets, Henry Ford undertook the purchase of raw material and its manufacture as required. This included the acquisition of iron and coal mines and timber lands, and the building of a railroad and line of steamboats. Raw materials are conveyed to the River Rouge plant, which is provided with coke ovens, blast furnaces and saw mills. This plant is equipped with electric furnaces, a cement plant, a glass factory, paper mill, foundry, and machine shops. All these being under the control of a single organization, are highly efficient in producing an economical manufacture of the Ford automobile.

In order to carry out his idea of making machines suitable for farm work, Mr. Ford took up the production of small tractors at the River Rouge plant where the factory for building them has a capacity of 750 "Fordsons," as these tractors are called, each day. These tractors are adapted to many kinds of work and have largely replaced horses.

The extended use of the Ford automobile has resulted from the ability of the company to produce a reliable small car at a low cost. This has been accomplished through Mr. Ford's originality in manufacturing methods, and his genius in building up a large organization, with the economies in buying, manufacture and distribution possible only in large scale operations.

The inexpensive Ford car and truck have materially changed conditions on the farm, enabling a farmer to command better and diversified markets, and to enlarge the social and intellectual contacts of himself and family. The Fordson tractor has increased his efficiency as an agriculturist, and particularly in the Northern States, by dispensing with horses, has enabled him to devote a greater area to crops not consumed on the farm.

To the workman, speedy transportation has opened up a larger field of operation. To the average citizen, the inexpensive car has developed many sources of pleasure heretofore enjoyed only by the wealthy few; and by making possible a more extensive and diversified travel, has created a better knowledge of our country and developed a broader vision.

In consideration of his rare inventive ability and power of

organization, by means of which he was able to effect high speed production of automobiles, revolutionizing the industry; and his outstanding executive powers and industrial leadership, THE FRANKLIN INSTITUTE awards its ELLIOTT CRESSON MEDAL to MR. HENRY FORD, of Detroit, Michigan.

WRIGHT "WHIRLWIND" ENGINE.

HALL OF THE INSTITUTE,
PHILADELPHIA, March 7, 1928.

No. 2890.

THE Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Wright "Whirlwind" Engine developed by Mr. Charles L. Lawrance, of Long Island, New York, now President and Chief Engineer of the Wright Aëronautical Corporation, of Paterson, New Jersey, reports as follows:

History: At the close of the World War the American aircraft engine industry was concentrated on water cooled engines. This was logical as the water cooled engines had been more successful than the early air cooled type and none of the latter had been developed in the higher powers.

In 1916 Mr. Charles L. Lawrance begun a development of air cooled engines of small power for airplane service in an endeavor to eliminate defects known to exist in previous types of rotary air cooled engines, such as gyroscopic effects, oiling trouble and improper gas distribution, and shortly after produced the three cylinder Lawrance L2 radial air cooled engine. This engine made some notable flights in small planes, but was superseded in a short time by the Wright "Gale" L4 Engine. This was also a three cylinder radial engine and developed 60 horsepower at 1800 r.p.m. It had a bore of 4.25″ and stroke of 5.25″ and weighed 140 pounds.

The success of these low power air cooled engines led to the securing of development contracts from the U. S. Government in 1920 and 1921 for nine cylinder radial air cooled engines of 140 and 200 horsepower. These two engines were developed simultaneously and both passed their fifty

hour acceptance tests in 1921. This second engine was the forerunner of the now famous Wright "Whirlwind" which we have under consideration. It has passed through seven successive models without changing the basic design or bore and stroke.

Following the success of the "Whirlwind" engine, engines of other makes and similar construction are now being produced and are in use.

Patents: Since the Wright "Whirlwind" Engine is the result of a continuous development extending over a period of years, the patents that have been granted on it are rather for modifications and improvements than for the engine as a whole. These patents have been granted to different persons but two of the important ones were issued to Charles L. Lawrance who designed the air cooled engine developed into the present type.

United States Patent No. 1,338,310 for which the application was filed September 6, 1918 was granted to Mr. Lawrance on April 17, 1920. This patent was for a lubricating system for high speed engines and the invention was for the purpose of avoiding the trouble previously caused by the heating of the crank pin. This invention avoids the trouble by using a hollow crank and crank pin forcing oil through them at high speed to conduct away the excess heat.

Five claims are allowed in this patent of which the third is as follows:

> "The combination in a high speed engine having a crank case, of a hollow crank, and bearings which receive oil through the interior of the crank and discharge lubricating oil into said case, a pump connected to deliver oil to the interior of said crank shaft and adjusted to deliver an excess of cooling oil above that required for lubricating the bearings supplied through said crank shaft, and a cooler connected to receive said excess oil from said crank shaft."

Another invention by Mr. Lawrance is for the "Big-End Construction for Radial Motors," and patent No. 1,398,194 was granted for this invention on November 22, 1921. Mr. Lawrance describes the purpose of the invention as follows:

> "My present invention relates to radial motors and particularly to that type in which a plurality of connecting rods are connected to a master piston rod about its bearing on a common crank pin.
>
> "The articulation of these several auxiliary connecting rods on the crank pin bearing of the master rod involves a variety of structural difficulties which had been only partially met and it was the object of my present invention to so improve this rather frequently used system of radial connecting rod assembly as to give a maximum of freedom to each rod with great strength and lightness."

The fourth of the seven claims allowed in this patent reads as follows:

> "In a motor of the class described, a crank assembly comprising a bearing sleeve on the crank pin and carried by one of the master rods, and a plurality of auxiliary connecting rods spaced about said bearing and connected thereto each by a joint consisting of a pair of longitudinally disposed end bearings, a central bearing rib, and a pin passing through said end bearings and the interposed end of a connecting rod, said connecting rod being slotted to permit the central bearing rib to contact with the lower face of the hollow pin."

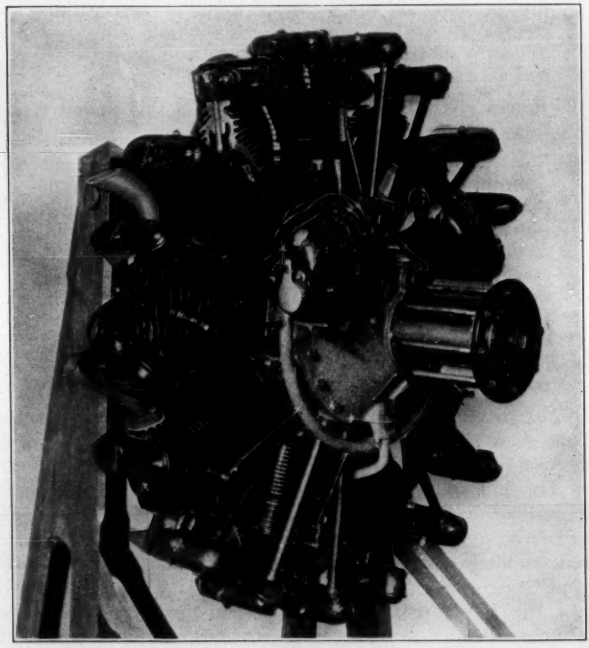
Design and Construction of the J5 Model: Figure 1 shows a front view of this model with propeller hub cap; Figure 2 shows a rear view.

The most efficient air cooling of an aviation engine is accomplished by causing air from the propeller slipstream to strike the cylinders laterally at right angles to the cylinder axis. This requires circumferential finning. The "Whirlwind" engine has aluminum alloy heads with cast fins to cool the valve seats and the combustion chamber. The cylinders proper are of steel with fins turned from solid forgings. They are screwed and shrunk into head castings using castor oil and graphite to lubricate and seal the threaded joint. The reason for radial cylinder design is due to the fact that more uniform cooling can be secured for each cylinder without necessity of an air distributing device.

The selection of an odd number of cylinders is due to

the use of the familiar four stroke-cycle of operation. If an even number of cylinders were used on a radial engine it would be necessary to fire them in pairs or else fire them successively during one revolution and skip the next, with consequent uneven impulse on the propeller.

FIG. 1.

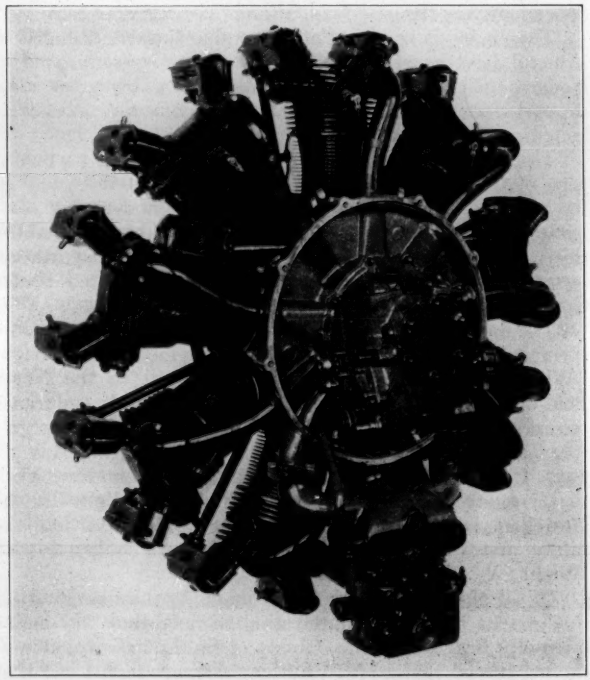


With an odd number, the firing order progresses around the cylinders skipping every other one so that the impulses on the propeller are uniform and all the cylinders are fired in two revolutions. Nine cylinders were selected for the "Whirlwind" engine so as to secure a 200 h.p. engine using

cylinders of size and design developed for the original Lawrance engine.

The mechanical balance of a radial engine involves the use of counterweights and takes into account the entire

FIG. 2.



weight of rods and pistons. The center of gravity of this system travels approximately in a circle if the stroke is reasonably short.

The design of the master rod involves an interesting study of knuckle pin travel so as to maintain an equal compression ratio in the cylinders.

Gas distribution is naturally an important consideration and is accomplished by three manifolds, each serving three cylinders. A single three barrel carburetor is used connected to the three manifolds.

Two separate sets of spark plugs are used and two high tension magnetos are provided working together or independently as the case may require.

The engine is mounted on a metallic support fastened to a metal fuselage structure now almost universally used in modern military or commercial aircraft. This gives ideal support for the engine with ample room for accessories including starter, etc.

The use of this engine is not confined to any particular type of airplane as is shown by the fact that it is used in the planes of ten mail carrying companies and twelve companies using planes for business purposes. It is used by thirty companies in passenger and other air transportation service—also in seven departments of the United States Government and seven foreign governments.

The daily press has made everyone familiar with the more spectacular performances of planes engined with Wright "Whirlwinds." These include Byrd's flight to the North Pole on May 9, 1926, Chamberlin and Acosta's endurance record of fifty-one hours, starting April 12, 1927, Lindbergh's solo flight from New York to Paris, France, starting May 20, 1927, Chamberlin's flight with a passenger from New York to Germany, a few days later, Maitland's flight to the Hawaiian Islands and many other records, proving the safety and reliability of modern airplanes equipped with Wright "Whirlwind" engines.

Of all these flights, the ones made by Lindbergh overshadow the rest. It is interesting to note that the engine originally installed in the "Spirit of St. Louis" was one of the ten special engines built for long distance flights and that it was still functioning satisfactorily when he landed in St. Louis on his return from his trip through the Southern Republics.

These engines were special only in the methods of inspection used and were so successful that all stock engines are now identical in material, inspection and workmanship with Colonel Lindbergh's engine.

It seems fitting that The Franklin Institute should recognize the vision, engineering skill and executive ability of Mr. Lawrance in pioneering the air cooled airplane engine and developing it to its present successful form. Included in this task was the development of new materials and facilities for building this remarkable mechanism and its testing. A trip through the shops of the Wright Aëronautical Corporation at Paterson, New Jersey, reveals the most precise machine work, the most painstaking care in inspection and assembly—elaborate proving apparatus is provided including wind tunnels, electrical dynamometers and all necessary meters and gauges, so that when an engine leaves their works, a Lindbergh may use it to arrest the attention of the world.

In consideration of his pioneer work in the development of the air cooled airplane engine, of his skill in bringing this engine to a high degree of perfection and of his ability in carrying out its manufacture, THE FRANKLIN INSTITUTE awards its ELLIOTT CRESSON MEDAL to MR. CHARLES L. LAWRANCE, of Long Island, New York.

THE WORK OF WILLIAM F. KIESEL, Jr.

HALL OF THE INSTITUTE,
PHILADELPHIA, April 4, 1928.

No. 2892.

THE Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Work of Mr. William F. Kiesel, Jr., of Altoona, in Railway Engineering, reports as follows:

William F. Kiesel, Jr., was born on September 1, 1866, at Scranton, Pennsylvania, and after serving an apprenticeship in the machinist trade in the shop of the Lackawanna Iron and Coal Company, prepared for Lehigh University from which he was graduated in 1887 with the degree of Mechanical Engineer. After graduation he spent a year in the service of the Lehigh Valley Railroad and of the Lackawanna Iron and Steel Company. He entered the office of the Mechanical Engineer of the Pennsylvania Railroad at Altoona, Pennsylvania, as draftsman, April 9, 1888. After a service of several years in this position he was appointed Chief

Draftsman on March 1, 1899; Assistant Engineer on July 1, 1900; Assistant Mechanical Engineer on September 1, 1902 and Mechanical Engineer on February 1, 1919, a position which he now holds.

One of the first things to which he gave his special attention was an improvement in the kind of water scoop used on locomotive tenders for taking water from the troughs while the train was running. The scoop then in use did not operate properly at high speeds. To overcome this difficulty Mr. Kiesel devised a balanced water scoop which was mounted on trunnions in such a way that it removed the difficulty and could be operated with ease. This device is described in U. S. Patent No. 531,191 issued to Mr. Kiesel on December 18, 1894, and is now the one in use on the Pennsylvania Railroad.

Mr. Kiesel next took up work on the compound locomotive and prepared designs covering several systems of compounding as applied to the Mogul locomotives (Class F2).

With the advent of the all steel passenger car, more powerful locomotives than those of the Atlantic type, then in general use, were required and Mr. Kiesel's work resulted in the design of the E6s type, more than eighty of which were built in 1912. These locomotives gave excellent results on the main line for a number of years but have now been generally replaced by still more powerful locomotives.

The trailer trucks used with this type of locomotive not having given satisfaction, Mr. Kiesel designed a form having outside journal bearings and with the truck frame so arranged that it served as an equalizer between the driving and trailer axles. This design of trailer truck proved to be so superior to previous ones that it is used with all locomotives of the Pennsylvania Railroad on which trailer trucks are used as well as on many locomotives for other railroads. United States Patent No. 929,768 issued on August 3, 1909, describes this truck.

Mr. Kiesel's next work in steam locomotive development was the design of the K4s (4–6–2) for passenger service and of the L1s (2–8–2) for freight service. The K4s is still the standard passenger locomotive for high speed main line work but the L1s has been superseded by other types.

In order to secure the use of steam expansively and economically in locomotives used for heavy service at a low speed, Mr. Kiesel developed a limited cut-off arrangement in which the locomotive was arranged to develop its maximum draw bar pull at 50 per cent. or a little greater cut-off. To insure starting, a small port was placed in each piston valve bushing; these ports were never closed and admitted steam to move the locomotive off a dead center. This arrangement is covered by United States Patent No. 1,307,821 issued on June 24, 1919.

The most successful high speed freight locomotive ever used on the Pennsylvania Railroad is the Mi (4–8–2) type. Mr. Kiesel was largely responsible for its design and in 1926 two hundred of this type were built.

While the work of Mr. Kiesel has been of a practical nature it has been largely original and his experience has enabled him to derive empirical rules and theoretical formulæ of high value. Some of these on tractive power and train resistance have been used in Professor W. R. Wood's book on "Locomotive Operation and Train Control."

The introduction of the electric locomotive has brought about new problems of design, many of them of a mechanical nature. Among such locomotives may be mentioned those used in the Hudson River tubes to New York City, which have been in successful use since 1910, and the electric locomotives used in the suburban train service from New York and from Philadelphia. Mr. Kiesel has been largely responsible for the mechanical parts of these, and especially for the oil pump used to lubricate them. The peripheral speed of the armature journal and the necessity of keeping the excess oil out of the motor windings have required the consideration of new problems which Mr. Kiesel has been largely responsible for solving. These pumps which are now applied to all L5 type electric locomotives are six cylinder, constant pressure and keep up a circulation of filtered oil through the bearings.

One thing that has added greatly to the safety of passenger travel and the security of goods in transportation is the development of the steel car. Mr. Kiesel became interested in this improvement for freight cars in 1897 and he has been

busied in their improvement ever since. The first all steel passenger coach to be used on a steam railway was put in service in 1906 and the replacement of wooden cars by steel cars is now practically completed—the present development being in the line of refinement of design.

Mr. Kiesel's many years of service in the mechanical side of railway engineering has brought him in contact with the details of much of the apparatus that is used in a practical way and for many of the improvements that he has made United States Patents have been granted to him. This list includes about a hundred different patents granted for inventions or improvements.

While a member of the A. S. M. E. Boiler Code Committee from 1916 to 1924 he was recognized as one of the outstanding leaders in the development and formation of Boiler Codes for Power, Heating and Locomotives. Many of the formulæ applicable only to locomotive boilers were the result of his years of experience in locomotive design and maintenance.

Mr. Kiesel is an active member of the American Railway Association and has served on many of its important committees and was Chairman of its Committee on Car Construction from 1912 to 1927.

In consideration of his numerous inventions of outstanding value in locomotive and railway car design and construction, THE FRANKLIN INSTITUTE awards its GEORGE R. HENDERSON MEDAL to MR. WILLIAM F. KIESEL, JR., of Altoona, Pennsylvania.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PURIFIED WOOD FIBERS.

SUPPLEMENTING previous work on permanence of alpha cellulose of pulps and half-stuffs, subjected to accelerated aging tests, samples of a new, white, rag half-stuff were treated with 1 and 3 per cent. bleach powder. These bleached samples thoroughly washed were made into hand-sheets and subjected to the usual 72-hour heat treatment at 100° C. Control and heated samples were analyzed for alpha cellulose content. The results which are tabulated below, check conclusively those previously obtained with the various grades of rag half-stuffs, and show clearly the effect of the presence of oxycellulose on the permanence of the cellulose fibers. Color permanence was also shown to be drastically lowered by the increased formation of oxycellulose.

Amount of Bleach, Per Cent.	Alpha Cellulose Content.		Loss in Alpha, Per Cent.
	Before Heating, Per Cent.	After Heating 72 Hours at 100° C., Per Cent.	
0	98.2	97.8	0.3
1	95.5	94.4	1.1
3	87.3	85.4	1.9

The viscosity determinations of the various pulps in copper ammonia solution before and after heat exposure are proving very interesting. In the viscosity determinations on sulphite, alpha cellulose, and old rag pulps, run to date, there seems to be a measurable drop in the viscosity curve (better, the time required for a certain volume under specified head to pass through a given orifice) of those samples which have been exposed. These results greatly strengthen the belief that the aging of cellulose pulps presents not alone a chemical change but also a physical one—a change in colloidal state, arrangement, or size of cellulose particle aggregation.

* Communicated by the Director.

Such changes, although they may be caused by or brought about by the chemical changes in the cellulose itself, may not necessarily show up by ordinary chemical determinations. This may be true even though basic changes have actually taken place in the pulps, changes which may seriously affect their use for permanent papers.

In the determination of the alpha cellulose content of the representative pulp samples before and after exposure to the 72-hour treatment at 100° C., the beta cellulose content appears to increase slightly as a result of the treatment. This increase probably bears some relation to the decrease in alpha cellulose content. However, with the data available, the bureau is not prepared as yet to say that the alpha cellulose loss is entirely converted into beta cellulose. In some instances the increase is not much greater than might be expected from experimental errors.

Papers have been subjected to various accelerated aging tests for the purpose of standardizing on the one best suited for permanence investigation. The following treatments were tried:

1. 100° C. in special circulating air oven for 24, 48, and 72 hours.
2. 95° C. in circulating oven in presence of humidified air for 72 hours.
3. Steam at atmospheric pressure for 2 hours.
4. Exposure to actinic rays from arc lamp. In preliminary work with the light test considerable difficulty was encountered in maintaining the humidity cabinet at sufficiently low temperature because of radiated heat from the arc. Various cooling devices are being tried in order to obviate this difficulty.

The test at 95° C. in humid air offers no particular advantages over the 100° C. exposure, and can undoubtedly be discarded. The 72-hour treatment at 100° C. seems to be by far the most convenient and satisfactory test, the two-hour steam treatment offering only one advantage, e.g., the short time required for its completion.

The entire series of submitted paper samples has been heated at 100° C. for 24, 48, and 72 hours and tested, together

with control samples for bursting strength, tensile strength, tear, and folding endurance. The 100 per cent. rag papers and alpha fiber papers show slight, and in most cases, no drop in bursting strength after heat treatment. Sulphite and 50 per cent. rag paper are, however, affected appreciably in this respect. The tensile strength is only of slight interest, even sulphite papers suffering no drop. The tearing test apparently is of some importance. Rag papers and alpha fiber papers show the highest retention of tearing force, rag and sulphite mixtures are next, while all-sulphite papers are most affected by the heat treatment. Judged by this test, sized papers are more permanent than unsized papers, the reverse being true in the case of fold retention. There is a fair degree of correlation between tear retention and fold retention. With very impermanent papers the tearing force is markedly lowered. However, the drop in folding endurance caused by a 72-hour heat treatment at 100° C. seems to offer the best indication of relative permanence of the various papers.

BOOKBINDING LEATHERS.

In coöperation with the New York Public Library a series of tests was made on samples of bookbinding leather treated and aged under the following conditions:

(*A*) Exposed to gas light and gas fumes for 2600 hours at 90° F.

(*B*) Same as (*A*) but treated with a mixture of 40 per cent. anhydrous lanolin and 60 per cent. neutral neatsfoot oil.

(*C*) Exposed to direct sunlight and air for 240 hours and daylight for 900 additional hours at average temperature of 90° F.

(*D*) Same as (*C*) but treated with the above mixture of oil.

From each of the samples three test pieces were cut and the results were the average of three individual tests.

The test results show very definitely that the original leathers were seriously damaged when subjected to gas fumes excepting one sample which showed only a normal difference in strength when compared to the original leather. One sample showed complete deterioration.

Exposure to light alone gave erratic results. In two samples there was little change and in two there was an unexplained increase in tensile strength, all the others showed some deterioration.

Exposure of the treated leathers to gas fumes also gave erratic results. In three samples there was an increase in strength while in all other cases there was a decrease.

Exposure of the treated leathers to light showed an increase in strength of all samples except one which remained the same.

Whereas the results given for the leathers treated with oil show the effects of the exposures in relation to the original strength of the leather, it is probable that the figures would be different if oil treated leather had been available on which original tests could have been made. The general effect of oiling leathers is to increase the tensile strength.

DRYING OF OILS.

SOME interesting experiments were made during the month on the drying of various oils as influenced by the light from the carbon arc. It was reported last month that linseed and tung oils would dry in the carbon arc in two hours as compared with several days in ordinary diffused light. This month many more oils were tested. Perilla oil set to touch in two hours. Oils such as candlenut, poppyseed, menhaden, and soya bean set to touch in four to seven hours. The so-called semi-drying oils, corn, cottonseed, and rubber seed oils, were found to dry in about 24 hours. In all cases the drying seems to be remarkably accelerated by the action of the carbon arc light. Films of the same oils are being exposed to diffused light in a drying cabinet. The linseed, tung, candlenut, perilla, and poppyseed became dry to the touch after four days under these conditions.

DETERMINATION OF SMALL AMOUNTS OF MOLYBDENUM.

IN tests of the KCNS-reduced molybdenum method for the colorimetric determination of small amounts of molybdenum

(which is used in the analysis of the bureau's standard samples) it has been found that the compound formed is one of quinquevalent molybdenum, and not of trivalent molybdenum as claimed by Krauskoff and Swartz (*Journal, American Chemical Society*, Vol. 48, p. 3021; 1926). Reduction of the molybdenum by zinc and acid or by stannous chloride, as generally specified, is not satisfactory as these gradually reduce molybdenum beyond the quinquevalent stage. A new method of reduction is being worked out, with most encouraging results.

LACQUERS FOR WEIGHTS.

THE bureau is now beginning a comparative study of the amount by which various lacquers change in weight with ordinary changes in the humidity of the atmosphere. A large number of uniform sheets of brass have been made for the preparation of samples, and it is expected that observations on the first of these will be started very soon.

As a part of this work, the bureau hopes to have some samples prepared by the various manufacturers of lacquered weights. Sheets for the preparation of a few samples will be furnished such makers as are willing to supply rather complete information concerning the material and methods used. The names of those who furnish such samples will not be published, but the bureau must be free to publish the results, together with the method of applying and treating the lacquer, and its composition, or other satisfactory methods of identifying it. These samples will be investigated by the bureau free of charge, and full reports on the results will be furnished at once to the maker who supplied each sample. It is hoped that this investigation will be of immediate assistance to these manufacturers in the selection of the most satisfactory material for lacquered weights. Sheets for the preparation of two samples have already been furnished one manufacturer.

FADING PHENOMENA TO BE STUDIED ON BYRD ANTARCTIC EXPEDITION.

L. V. BERKNER, Assistant Radio Engineer, Bureau of Standards, is now on board the ship *City of New York* of the

Byrd Antarctic Expedition en route to the antarctic regions. Mr. Berkner, in addition to his duties as a radio officer of the expedition, will make an investigation of fading phenomena, particularly of high-frequency transmissions. The equipment for this work consists of two special high-frequency receiving sets loaned by the Westinghouse Electric and Manufacturing Company to which fading recorders have been adapted by the bureau. These recorders are similar to those used by the Bureau of Standards in previous fading investigations, and the method used will be the same.

It is expected that this investigation will give information on the effect of the concentration of the earth's magnetic field at the south magnetic pole, of auroras, temperature, height of the radio reflecting layer, and many other phenomena which affect radio transmission. Mr. Berkner will make observations upon selected stations, and some special transmissions may be arranged.

The expedition will be in the antarctic regions for sufficient time to give observations throughout both the daylight and dark months of an antarctic year. The bureau will keep in touch with the work by means of radio communication.

FILTERS FOR CHANGING THE COLOR TEMPERATURE OF INCANDESCENT SOURCES TO MEAN SUNLIGHT.

IN connection with an extensive investigation leading to the development of a large number of reproducible liquid filters for converting the color of incandescent light sources to sunlight and other high color temperatures, a filter was designed to convert the color and energy distribution of an incandescent Mazda-C lamp at 2848° K. to that of the sun outside of the earth's atmosphere. It was hoped that this might serve as a suitable daylight filter, inasmuch as but little of the sun's energy (in the visible spectrum) is selectively absorbed by the atmosphere. In other words the relative spectral energy distribution of the sun outside the atmosphere should be closely like that of the sun plus blue sky or like that of an overcast sky.

The color of this source and filter combination has been compared with that of overcast sky on several days between

September 14 and September 29, 1928, the autumnal equinox period. At certain times on four different days the natural and artificial daylight were in practically perfect color match. At other times the natural daylight was slightly yellowish, purplish, or bluish, relative to the standard.

Standard artificial daylight is thus available, accurately reproducible from specification, and may be readily prepared in any laboratory. The specifications of this filter are similar to those of other Davis-Gibson filters. The exact proportions of the ingredients are as follows:

A.

Copper sulphate ($CuSO_4.5H_2O$)	3.125 grams
Mannite ($C_6H_8(OH)_6$)	3.125 grams
Pyridine (C_5H_5N)	30.0 ml.
Water (distilled) to make	1000.0 ml.

B.

Cobalt ammonium sulphate ($CoSO_4.(NH_4)_2SO_4.6H_2O$)	25.470 grams
Copper sulphate ($CuSO_4.5H_2O$)	25.000 grams
Sulphuric acid (Sp. gr. 1.835)	10.0 ml.
Water (distilled) to make	1000.0 ml.

One centimeter of each of solutions *A* and *B* are contained in a double cell having three plates of borosilicate crown glass (refractive index, D line = 1.51) each 2.5 mm. thick.

Complete spectrophotometric data will be sent upon request.

MEASUREMENT OF ELASTIC STRAINS IN CONCRETE STRUCTURES.

A TEST has been made recently to determine the practicability of a method which could be used in field tests of concrete structures, for distinguishing between the elastic strains produced by stress and those resulting from changes in temperature and humidity and from plastic flow or yield. In this method small blocks of concrete are cut out of the structure, measurements are made of the elastic recovery which takes place in these blocks as they are relieved from the forces acting when in the mass. The changes in strain accompanying the removal of the blocks were determined readily by means of a hand strain gauge. To facilitate the removal of the blocks it was suggested that each should be cast in a U-shaped trough or form. The principal object

of the test was to determine whether the presence of the form material would appreciably affect the strains in the block and whether the block could be cut out without injury to the gauge lines.

A concrete prism 30 by 30 inches in cross section and 36 inches in height was made for the test. The prism contained one removable block near the mid-point of each of the four lateral faces. Each block was in the form of a prism 5 by 5 inches in cross section and 20 inches in height. One of the forms for shaping the blocks was made of sheet metal about .03 inch in thickness. The other three were made of wall board of three different thicknesses. All were given a thin coat of paraffin to prevent bonding with the concrete. Plugs were set in the concrete for use in taking strain gauge readings in three gauge lines on each lateral face of the prism, one gauge line being in the removable block and the other two midway between the edges of the block and the prism.

The prism was placed in a testing machine and a compressive load of 600 lbs./in^2. applied. After taking strain readings one of the blocks was removed by cutting the concrete along each end of the block. Although this required a cut about 5 inches in length and 5 inches in depth along each end of the block these were made easily with a small air drill. The load on the prism was then released and strain gauge readings were made. The same operation was followed in removing another block from the prism.

The results of the tests indicate that the blocks, when separated (except at the ends) from the prism by thin forms, were cut out without a noticeable injury to the gauge lines. It was found, however, that the strain in the block cast into the sheet steel form was only about 70 per cent. of the average strain in the adjacent gauge lines, whereas for the blocks cast into wall board forms the strains were on the average about 30 per cent. greater than in the adjacent concrete. These results indicate that some provision should be made when using metal forms to prevent the steel form taking such an appreciable amount of stress as to affect the strain in the concrete block. They show further that wall board on account of its greater thickness and lack of rigidity is not a suitable material for such forms. Apparently, the method

can be made practicable for separating the elastic from the inelastic strains measured in concrete.

REPORT OF STANDARD ZETTLITZ KAOLIN TEST.

At its Copenhagen meeting, the International Union of Pure and Applied Chemistry voted to undertake the preparation and distribution of an international standard sample of Zettlitz kaolin and charged the Ceramic Society of Czecho-Slovakia with the duty of carrying out this resolution. This society established a permanent committee to prepare, distribute, and to act as custodian for this standard sample. Samples of this standard may be secured by application to The Ceramic Society of Czecho-Slovakia, Prague, Czecho-Slovakia. Samples of this standard have been distributed to the countries belonging to the Union for analysis and test, and it is hoped that a comparative study of the results obtained will lead eventually to the adoption of international methods for the analysis and testing of clays for ceramic purposes.

The present report contains the results obtained in the study of the standard kaolin at the Bureau of Standards made in accordance with the methods adopted by the American Ceramic Society and also other methods in use at the bureau.

Chemical Analysis.

	Per Cent.
Silica (SiO_2)	46.90
Alumina (Al_2O_3)	37.40
Ferric oxide (Fe_2O_3)	.65
Phosphorous pentoxide (P_2O_5)	.08
Titania (TiO_2)	.18
Zirconia (ZrO_2)	.007
Manganese oxide (MnO)	.007
Calcium oxide (CaO)	.29
Magnesium oxide (MgO)	.27
Barium oxide (BaO)	.02
Strontium oxide (SrO)	.006
Chromic oxide (Cr_2O_3)	.015
Vanadium trioxide (V_2O_3)	.002
Potassium oxide (K_2O)	.84
Sodium oxide (Na_2O)	.44
Sulphur trioxide (SO_3)	.03
Loss on ignition (1050–1100° C.)	12.95
Total	100.087

SUMMATION OF PHYSICAL TESTS.

Test.	Clay.	50/50 Clay-Flint Mix.
Softening point	Above cone 34 (1755° C.)	
True specific gravity	2.633	
Dry volume shrinkage	25.8 per cent.	16.1 per cent.
Dry linear shrinkage	7.9 " "	5.1 " "
Water of plasticity	46.4 " "	29.8 " "
Shrinkage water	17.1 " "	10.4 " "
Pore water	29.3 " "	19.4 " "
Dry transverse strength	261 lbs./in².	116 lbs./in².

In the determination of the firing behavior, values were obtained on specimens of clay and of 50/50 clay-flint mixtures fired to cones 2, 4, 6, 8, 10, 12, 14, 16, and 18. Only the results at cone 12 are reported herewith.

Test.	Clay.	50/50 Clay-Flint.
Porosity	25.4 per cent.	32.0 per cent.
Fired volume change	33.35 " "	8.75 " "
Linear change	12.75 " "	3.35 " "
Apparent specific gravity	2.545	2.555
Bulk specific gravity	1.90	1.75
Absorption	12.9 per cent.	17.5 per cent.
Fired transverse strength	4,290 lbs./in².	1,660 lbs./in².
Modulus of elasticity	5,911,000 lbs./in².	
Coefficient of expansion per degree Centigrade (Interferometer method)	6.74×10^{-6}	12.94×10^{-6}

A detailed report of the tests made, and of the apparatus and methods used in making the tests, is being prepared and will be available in the near future.

SPARK ACCELEROMETER.

IN the course of current work on motor fuel research, it has been necessary to devise apparatus of increased precision for the measurement of automotive engine acceleration.

The acceleration of interest is that occurring in the short interval after the throttle is opened before the engine attains full speed. At first this was obtained from successive readings of a chronometric tachometer. However, in addition to being inaccurate and involving the personal equation, the tachometer, reading only once a second, obscures some transient phenomena.

The apparatus devised to overcome these difficulties is constructed almost entirely of parts commercially obtainable at low cost. It consists of a sprocket, coupled to the engine through a one-position claw clutch, which draws paper tape, of the same size and with the same perforation as 16 mm. motion picture film, between electrodes across which a spark is periodically discharged. This spark is timed by a tuning fork, which breaks the primary circuit of an automobile ignition coil. The record consists of a series of holes in the tape, the distance between any two holes being proportional to the mean engine speed in that time interval.

In order to facilitate measurement and computation of the results, the tuning fork was adjusted to give a frequency of 360 cycles per minute. Measurement is made by passing the tape over a sprocket identical with the one attached to the engine. A microscope is trained on the tape, and the sprocket is revolved until a spark hole is under the cross hair. Reading is made on a micrometer head graduation in degrees which is carried on the sprocket shaft. Since the tuning fork splits a minute into 360 parts and the micrometer head splits a revolution into 360 parts, differences of successive readings give revolutions per minute directly.

Strictly speaking, the data give only displacement and time precisely, and acceleration is obtained only approximately by double numerical differencing. Mathematical analysis shows, however, that the error thus introduced is negligible for the purposes of the present investigation. With this apparatus, speed can be measured six times a second, with a probable error for a single measurement of less than 1 r. p. m.

STANDARDIZATION OF DIESEL ENGINE FITTINGS.

PLANS for standardization in the Diesel engine field are described in a bulletin of the American Society of Mechanical Engineers. The bulletin points out that certain small parts, such as piston rings and spray valves, are manufactured by specialty concerns and that standardization would enable these manufacturers to contribute largely to the reduction of engine-making costs. A committee of the oil and gas power division is at work on the subject.

Eggs. E. M. BAILEY (Connecticut Agric. Ex. Station Bulletin 295, 314–315, 1928) states that large air spaces accompanied by low ammonia content indicate eggs held at low temperatures or in cold storage. Large air spaces accompanied by high ammonia content indicate eggs held under less favorable conditions, e.g., those held too long by either the producer or the retailer.

J. S. H.

Use of Carbon Tetrachloride plus Air for the Decomposition of Sulphides and Related Compounds. K. BRADDOCK-ROGERS (Thesis, Graduate School, Univ. of Penn., 1928, 1–21) has devised the following procedure for the preparation of sulphur-free carbon tetrachloride. He treats 3 parts of carbon tetrachloride with 2 parts of a 1 : 1 mixture of ammonia water and sulphate-free hydrogen peroxide, repeats the treatment several times, dries over calcium chloride, and distils. The entire process is repeated until a product is obtained which is shown to be sulphur-free by the following test. The carbon tetrachloride is kept at a temperature of 60° to 65° C.; one liter of air, free from carbon dioxide and moisture, is drawn through it in 40 minutes; and the gaseous mixture is heated to a temperature of 750° to 800° C., then passed into ammoniacal hydrogen peroxide solution which is free from sulphates. The resulting solution is boiled to expel the excess of ammonia, acidified with hydrochloric acid, and tested for the presence of sulphates with barium chloride solution.

Certain sulphides, selenides, and tellurides were completely decomposed and chlorinated by treating them with a mixture of air and vapor of the sulphur-free carbon tetrachloride at elevated temperatures. Of the sulphides, sphalerite, pyrite, cinnabar, bismuthinite, chalcopyrite, nickel matte, copper matte, and palladous sulphide were decomposed, and their sulphur content rapidly and conveniently oxidized prior to quantitative determination of that element. Pyrrhotite, marcasite, arsenopyrite, stibnite, tetrahedrite, cobaltite, molybdenite, galenite, enargite, sylvanite, and tiemannite were completely decomposed, but the quantitative determination of their sulphur or selenium content was not made. The procedure was also used for the complete decomposition of the selenides, berzelianite and zorgite, and of the telluride altaite, and the quantitative determination of their selenium and tellurium, respectively.

J. S. H.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

QUANTITATIVE RELATIONS OF THE COUNTER-CURRENT WASHING PROCESS.[1]

L. Silberstein.

A MATHEMATICAL treatment of the so-called counter-current process of widespread use in chemical manufacture. The general conditions of the process are expressed in the form of recurrence equations. By means of these equations the cases of a three-tank, a four-tank, and a five-tank system are dealt with in detail, and formulas are developed giving directly the concentration of the solute in each tank after any number of operations, including the limit-values of the concentrations for an indefinitely continued working of the process.

* Communicated by the Director.

[1] Communication No. 340 from the Kodak Research Laboratories and published in *Ind. Eng. Chem.* **20**: *899. 1928.*

Respirators for Protection Against Poisonous Sprays.—(United States Public Health Service.) Surgeon General H. S. Cumming, of the U. S. Public Health Service, has recently announced (Public Health Bulletin No. 177) the results of an investigation undertaken at the request of a committee appointed by the National Safety Council. This investigation has been made by the United States Bureau of Mines and the National Safety Council in cooperation with the United States Public Health Service to determine the value of respirators as a means of protection from the hazard of spray painting resulting from exposure to lead, benzol, and silica. The specific questions proposed by the National Safety Council to be answered were as follows:

1. What filtering material, if any, is adequate?
   (*a*) To reduce the lead content of the air to which a spray coater is exposed from 200 milligrams per cubic meter to 0.6 milligram per cubic meter?
   (*b*) To reduce the amount of benzol under similar conditions from 2,000 to 75 parts per million?
   (*c*) To reduce the number of silica particles under similar conditions from 200,000,000 to 100,000 per cubic meter as determined by the Palmer method?
2. How long would such a layer function?
3. How do certain typical masks now available measure up to this standard?

The concentrations stated above for lead and benzol should not be construed as being those to which spray painters are commonly exposed. They represent more nearly the high concentrations which can quickly cause sickness and are to be considered as extremes.

It may be stated, as a result of the tests, that in general the respirators with cotton, paper, or fabric filters remove 90 per cent. or more of the lead from air carrying paint mist. These respirators restrain none of the solvent vapors, however; but the addition of a canister or cartridge of activated charcoal to the respirator removes all solvent vapors until the charcoal becomes saturated.

The useful life of filters is determined by their increase in resistance, which necessitates changing for fresh filters at intervals of several hours. When charcoal is saturated, the cartridge must be exchanged for a fresh one. Canisters of the size used with gas masks may last for weeks before a change is necessary.

The respirators were somewhat less efficient against the silica dust sprays, but they restrained 24 per cent. or more of the dust from the air passed through them; most of them were more than 50 per cent. efficient.

NOTES FROM U. S. BUREAU OF MINES.*

NEUTRALIZATION OF ACID MINE WATERS.

THE neutralization of acid mine waters, which drain into rivers and creeks, thereby constituting a serious sanitary problem, can be successfully accomplished, so far as chemical and mechanical factors are concerned, declares the United States Bureau of Mines. The final problem is, however, one of economics. In that aspect, it must be considered separately for specific sections or communities. The factors involved are of such a nature that one hard and fast rule can not be applied with equal satisfaction to all cases.

The pollution of streams has received much attention during the last few years, and although there are many other and more serious forms of pollution, the problem of acid mine drainage is important in certain sections of the country, particularly in Pennsylvania. At the request of the United States Public Health Service, the Bureau of Mines undertook to determine some of the factors contributing to formation of acid mine waters, the yearly variation in quantity and quality of drainage, effect of mining methods, and various other questions arising in connection with the problem; some attention was also given to its economic phases.

A stream having a number of mines draining into it was selected for observation in both high-sulphur and low-sulphur bituminous-coal districts. These mines and streams were visited in both wet and dry seasons to note the quantity and variations in acidity of mine drainage and the subsequent effect on streams. The streams were sampled at regular intervals of about one-half mile, unless entering streams or unusual conditions warranted more frequent samples.

Mine samples showed wide variations in acidity, but indicated that drippers and samples from fresh working faces were almost invariably alkaline or but faintly acid because of the presence of bicarbonates or dissolved carbon dioxide in the

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water. On the other hand, water from inactive or abandoned sections was almost invariably acid to a degree determined largely by the period that the sections had been idle.

Gobbed material, both inside and outside the mines, is undoubtedly an important source of acid water; but whether the practice is to gob rock and high-sulphur coal inside or outside the mine, the general acidity of the water from the different mines does not show appreciable differences. Outside gob piles are under the most favorable conditions for liberating acid, more so than if the gob material were inside; therefore it seems that less damage would be done if the acid-forming wastes were left inside. If gob material could be placed in dry sections of the mine and sealed off to exclude air, the minimum formation of acid might be expected.

Water from mines having a limestone floor would be expected either not to be acid or at least to be less so than water from mines in the same district not having a limestone floor. No marked difference has so far been observed in such waters, probably because after a short time the drainage channels become coated with iron oxide which adheres tenaciously to the stone and protects it from contact with the water.

Water from high-sulphur-bearing coal beds is more acid than that from low-sulphur beds.

Abandoned workings are known to have given off water of approximately the same quality and quantity up to at least 15 years after being abandoned. One abandoned mine has been giving off highly acid water for 45 years to date; no caving has yet occurred in this mine. Four others exhibit the same characteristic after having been abandoned 35 years. Twenty-five abandoned workings showed about the same acidity as eight active mines in one district studied, but in the other district seven abandoned mines showed only about one-half the acidity of the other 17 active mines.

Seasonal variations play an important part in the effect of mine drainage on streams. The maximum stream volume at flood stage in such localities as those studied may be many times the average volume because of the rapid run-off. Heavy rains of short duration, therefore, dilute the water to the extent that it may be considered harmless; mine drainage is not in general increased unless slower soaking rains occur. On the

other hand, at periods of low water, usually in August or early September, the stream volume may be, and often is, almost entirely mine drainage.

So far little opportunity has been afforded for observing the effect of a definite quantity of acid in streams. With one exception, the entry of drainage from successive mines resulted in building up an acidity which decreased only slightly until the stream entered a small river.

At the present time there seems to be no solution of the problem of stream pollution other than that of chemical neutralization. One method that might be used to treat large volumes of water is to feed ground limestone or lime to the raw water, using a baffled flume to mix the lime well, and then permitting the water to flow into natural or artificial settling basins of sufficient capacity to retain the water for four or five hours. During this time the hydrated oxides of iron will settle out and the effluent water will be neutral or alkaline, somewhat harder, but almost clear, and harmless for most purposes if the treatment is carefully controlled. Of the methods now in use this is the cheapest in first cost and the most simple in operation, but it leaves the sludge as a material too thin to shovel and too thick to pump. Its subsequent removal and disposal is likely to prove as much of a problem as the original acid neutralization now appears to be.

The solution of the problem of drainage disposal after coal areas have been mined out and acid water still continues to flow for an indefinite time is also uncertain. One possible solution is to seal abandoned mines as so to exclude the air and thus prevent further oxidation of the pyrite. It seems likely that water from such mines would become pure again in less time than if they were not sealed.

Considerable improvement in certain sections that are now being polluted by water from abandoned workings might be accomplished by sealing the mines; the cost would not be great and the process does not appear difficult in most cases. The sucess of this scheme seems very probable because it has repeatedly been shown that where abandoned mines are sealed either by natural caving or by building seals, the water is suitable for all ordinary uses, sometimes even for drinking water.

MANUFACTURE OF WAX CRAYONS FROM COAL TAR.

The suitability of wax extract from coal tar produced in the low temperature carbonization of coal for use as a base in the manufacture of colored wax crayons is being investigated at the Pittsburgh Experiment Station of the Bureau of Mines. Several commercial colored crayons have been analyzed and similar crayons have been made up using the tar wax. From experiments so far made this wax appears very well suited to the purpose. It has a high melting point, which doubtless will render its use advantageous in making crayons for particular purposes.

FUSAIN IN PITTSBURGH COAL.

A general investigation of the inert materials in Pittsburgh coal of the Youghiogheny district is being made by the Bureau of Mines. In the course of this work it is found that the fusain or mineral charcoal, is distributed in thin partings quite widely over the whole bed, that is, in some localities most of it will be found at the top of the bed and in others at the bottom or in the middle. Some of these fusain partings are quite hard due to a high calcium carbonate content, whereas others are soft and contain very little calcium carbonate. The total fusain content in the main coal seam of one mine was found to be of the order of 3.5 per cent. It has been shown that segregated fusain in a coking coal has a very deleterious effect on the coke produced therefrom. It weakens the coke structure. The precise effect of evenly distributed fusain, however, has not been determined.

LESS FINELY CRUSHED GRAINS NOW YIELD TO FLOTATION.

It has generally been held that for the treatment of ores by the flotation process, crushing to minus 65 mesh is required. This was the size limit of grains which experience seemed to indicate, when only oils were used chiefly. Experimental work at the Moscow, Idaho, field office of the Bureau of Mines shows that sands crushed to not nearly this degree of fineness can be readily floated. In some of the work at that station, as coarse as 20 mesh sands are amenable to flotation. Even coarse sands that expose at their surfaces very small specks of the floatable mineral may be lifted.

This broadening of the field of flotation is due to the development in recent years of the "promoter" class of reagents. These substances so greatly increase the flotative vigor of a mineral that correspondingly larger grains may be lifted. Flotation is rapidly moving into the size range of table concentration and the cost of crushing for flotation gradually being reduced.

CALORIMETRY OF METAL OXIDES.

A new type of calorimeter for the study of metal oxides has been developed at the Pacific Experiment Station of the Bureau of Mines, Berkeley, California, and is now being operated at that station. Despite the great technical importance of data on heats of oxidation of common metals, little work on the subject has been done in recent years. Classical values used by metallurgists or chemists often date back more than 50 years. Modern requirements, especially for critical thermodynamic studies of smelting processes, necessitate more accurate determinations.

The bomb type of calorimeter, in which metal is burned with oxygen under pressure, although of great practical use for fuels, is unsuitable for metals when high accuracy is desired, and indirect methods are preferable. The chief of these is calculation from measured heat of solution of metal and oxide in the same concentration of acid. Ordinarily oxides are rapidly and metals slowly dissolved by acids. The new calorimeter has been specially designed to enable both types of determinations to be made in the same instrument, thus assuring comparable results for oxide and metal.

An unusual feature of the Bureau of Mines' calorimeter is a small built-in boiler in which ethyl bromide is evaporated at 25° C. at a rate just sufficient to neutralize the heat of solution of the metal. In this way experiments of many hours' duration may be made with negligible undeterminable loss of heat. The amount of ethyl bromide evaporated is weighed and the heat calculated therefrom, even though actual temperature change did not occur. Corrections necessary with other methods, involving the heat content of the calorimeter, are thus avoidable, or become satisfactorily minute.

Separation of Aluminium and Beryllium. I. M. KOLTHOFF and ERNEST B. SANDELL of the University of Minnesota (*Jour. Am. Chem. Soc.*, 1928, *50*, 1900–1904) recommend the use of ortho hydroxyquinoline for the separation of aluminium and beryllium. A 5 per cent. solution of the reagent is prepared, using double normal acetic acid as the solvent. The solution of aluminium and beryllium should be only slightly acid; it is warmed to a temperature of 50° to 60° C.; an excess of the solution of ortho hydroxyquinoline (also called oxine) is added; then double normal ammonium acetate solution is slowly added until a permanent precipitate forms and a large excess of this reagent is present. The aluminium is precipitated as its salt of ortho hydroxyquinoline, which has the formula $Al(C_9H_6ON)_3$ and contains 11.10 per cent. of alumina, Al_2O_3, when dried at 120° to 140° C. Beryllium remains in solution. The beryllium may be precipitated in the filtrate from the aluminium by means of ammonia after heating almost to boiling.

J. S. H.

Acetic Acid as a Solvent. ARTHUR W. DAVIDSON of the University of Kansas (*Jour. Am. Chem. Soc.*, 1928, *50*, 1890–1895) finds that many salts, especially halides and nitrates, are soluble in pure acetic acid, while sulphates are very slightly soluble in that solvent. Reactions involving double decomposition occur quite readily in acetic acid solutions, but solvolysis does not take place to any marked extent. J. S. H.

Origin of the Metal in Meteorites. GEORGE P. MERRILL (*Proc. U. S. Nat. Museum*, 1928, *73*, Article 21, 1–7) has evolved a theory concerning the origin of the metal in meteorites. Meteorites are volcanic products. They contain lawrencite or ferrous chloride. When first formed, large quantities of chlorides are present. The heated atmosphere of hydrogen or other reducing gas at the fountain source of the meteorite reduces chlorides to the metallic state. J. S. H.

Occurrence of Carotin in Honey. H. A. SCHUETTE and PHYLLIS A. BOTT of the University of Wisconsin (*Jour. Am. Chem. Soc.*, 1928, *50*, 1998–2000) have isolated at least one of the pigments of buckwheat honey by means of petroleum ether in the presence of ethyl alcohol and calcium sulphate, and have identified it as carotin. J. S. H.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, October 17, 1928.)

THE stated monthly meeting was called to order at eight-eighteen p.m. by Mr. Henry Howson, Vice-President.

The Secretary announced that the minutes of the last stated meeting, the Medal Day meeting held on May sixteenth, had been published in full in the June number of the Journal and that an extended description of Medal Day exercises had been published in the Journal for August. He therefore moved that the minutes and description of the meeting be approved as printed in the Journal. The motion was seconded and unanimously adopted.

The Secretary made the following report concerning changes in membership which have taken place since the last stated meeting: Ten new Resident members, thirteen Non-Resident and one Student member, and eleven deaths, which are reported in the Journal.

There being no further business, the Chairman called for the paper of the evening, which was to be delivered by the Secretary of the Institute on "Present and Proposed Activities of The Franklin Institute."

The meeting adjourned at nine-twenty-eight p.m., after which a moving picture film made in the scientific museums of Europe a year ago was shown to the membership of the Institute.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, October 3, 1928.)

HALL OF THE COMMITTEE,
PHILADELPHIA, October 3, 1928.

DOCTOR GEORGE S. CRAMPTON *in the Chair.*

The following reports were presented for final action:

No. 2875: Ruths' Steam Accumulator.

The purpose of this device is to provide a means of storing steam in connection with a boiler plant in order to meet higher steam requirements without forcing the boilers beyond their rated capacity. To secure this result steel cylindrical storage tanks with hemispherical ends are provided in which water at a temperature above the atmospherical boiling point is stored.

Whenever the steam driven machines do not make use of the steam generated in the boilers, the excess steam passes through a one-way valve into the storage tank in which it is forced into water through distributing pipes raising both the temperature and pressure of the water.

Whenever the machines demand more steam than the boilers provide, steam from the storage tank passes through an outlet valve to supply the deficiency.

This steam accumulator is extensively used in European countries and is being introduced in the United States.

This report recommended the award of the John Price Wetherill Medal to Doctor Johannes Ruths of Djursholm, Sweden, "In consideration of the excellence of design of the control equipment and the adaptation of sound principles to the successful production of large steam storage apparatus."

No. 2893: Gas Carburizing Apparatus.

The use of this method is for carburizing, carbonizing, or case hardening steel articles by means of a rotary carburizer which is heated by gas and is kept in rotation during the process.

The articles to be carburized are placed in the retort, the carburizing compound or gas is then added and the fuel gas applied. The temperature at which carbonization begins is about 1350 degrees F. and the depth to which the hardening extends is approximately proportional to the time of operation.

The furnace in which the process is carried on is supported on an axle extending crosswise upon which it can be tilted. For loading it is tilted with the mouth upward, for carburizing it is kept horizontal. When the operation is finished it is tilted with the mouth downward to empty the contents into a quenching tank.

This report recommended the award of the Edward Longstreth Medal to Mr. Adolph W. Machlet, of Elizabeth, New Jersey, "In consideration of his improved method of case hardening and the construction of the apparatus for that purpose whereby the cost of case hardening is reduced, a greater uniformity of hardened surface secured and the quality of the work kept under control and thereby improved."

The following report was presented for first reading:

No. 2883: Monroe Calculating Machine.

GEORGE A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, October 10, 1928.*)

RESIDENT.

DR. JOHN MCARTHUR HARRIS, JR., Chemical Engineer, Sun Oil Company, Norwood, Pa. For mailing: 105 West Walnut Lane, Philadelphia, Pa.

MISS ELISE NACHMAN, Teacher, Fitzsimons Junior High School. For mailing: 4617 Pulaski Avenue, Philadelphia, Pa.

MR. ALAN REED, Wyncote, Pa.

MR. JOHN R. WILLIAMS, President, Electric Storage Battery Co., Eighteenth Street and Allegheny Avenue, Philadelphia, Pa.

NON-RESIDENT.

MR. CLARENCE W. HANSELL, Electrical Engineer (Radio), Radio Station, Rocky Point, N. Y. For mailing: 115 Tuthill Street, Port Jefferson, N. Y.

MR. WILLIS A. NAUDAIN, Electrical Engineer, Meter Engineer, Delaware Electric Power Co., 834 Market Street, Wilmington, Delaware. For mailing: 304 West Fourteenth Street, Wilmington, Delaware.

DR. WILLIAM S. MASON, Banker, 1401 Ridge Avenue, Evanston, Illinois.

MR. DEL A. SMITH, General Manager, Department of Street Railways, City of Detroit. For mailing: 4373 West Philadelphia St., Detroit, Michigan.

CHANGES OF ADDRESS.

MR. FRANK AIKEN, 474 West Manheim Street, Germantown, Philadelphia, Pa.

DR. GELLERT ALLEMAN, Wallingford, Pa.

DR. H. D. ARNOLD, Bell Telephone Laboratories, Inc., 463 West Street, New York City.

MR. A. F. BABCOCK, Traffic Department, 1835 Arch Street, Philadelphia, Pa.

MR. CARL G. BARTH, 229 Park Avenue, Prescott, Arizona.

MR. A. W. BERRESFORD, 1 Fifth Avenue, New York City.

MR. STERLING H. BUNNELL, 27 William Street, New York City.

MR. HENRY H. COLLINS, 1518 Walnut Street, Philadelphia, Pa.

MR. JOHN F. CONAWAY, 1913 North Twelfth Street, Philadelphia, Pa.

MR. GEORGE M. DAVIDSON, 211 North East Avenue, Oak Park, Illinois.

MR. JOHN F. DREYER, JR., 232 West Walnut Lane, Germantown, Phila., Pa.

MR. WILLIAM DUBILIER, Patents Corporation, 10 East Forty-third Street, New York City.

MR. CLARENCE ERROL FERREE, Wilmer Ophthalmological Institute, Johns Hopkins Hospital, Baltimore, Md.

MR. EDWIN FRANK, 1023 Shepard Avenue, Milwaukee, Wis.

DR. F. W. FRERICHS, 4557 West Pine Boulevard, St. Louis, Mo.

MR. HARRY A. GOULD, 119th Street and Morningside Drive, West, Butler Hall, New York City.

MR. GEORGE R. HALL, Room 711, 50 Broadway, New York City.

MR. THOMAS W. HICKS, 1415 Thayer Avenue, Brentwood Heights Station, Los Angeles, California.

MR. L. H. KINNARD, Bell Telephone Company, 1835 Arch Street, Philadelphia, Pa.

MR. H. W. LILLEBRIDGE, 226 West Jackson Street, Philadelphia, Pa.

DR. JOHN M. MILLER, 1010 West Upsal Street, Germantown, Phila., Pa.

MR. JOSEPH W. MYERS, 205 South Webster Street, Jackson, Michigan.

MR. FOSTER NOWELL, Engineering Department, 1635 Arch Street, Philadelphia, Pa.

MR. H. H. PLATT, Boulevard Dominique Durandy, St. Jean Cap Ferrat Alpes Maritimes, France.

MR. C. H. QUINN, 541 Monadnock Building, San Francisco, California.

MR. TALBOT M. ROGERS, 6 South Dodd, Princeton, New Jersey.

DR. G. D. ROSENGARTEN, Malvern, Pa.

MR. JAMES L. SCHWANK, Alden Park Manor, Germantown, Philadelphia, Pa.

MR. F. R. SHUMAN, Bell Telephone Company, 1835 Arch Street, Philadelphia, Pa.

DEAN AUGUSTUS TROWBRIDGE, Princeton University, Princeton, N. J.

MR. E. T. TURNER, 170 North Beacon Street, Hartford, Conn.

MR. C. D. TUSKA, 717 West Mt. Airy Avenue, Mt. Airy, Philadelphia, Pa.

MR. S. M. VAUCLAIN, The Baldwin Locomotive Works, 123 South Broad Street, Philadelphia, Pa.
MR. WALTER C. WAGNER, Edison Building, Ninth and Sansom Streets, Philadelphia, Pa.
MR. J. E. WAIDLICH, Bell Telephone Company, 1835 Arch Street, Philadelphia, Pa.
MR. ALFRED E. WALLER, 110 White Plains Road, Bronxville, New York.
MR. E. R. WHITNEY, 6745 Lawnton Avenue, Oak Lane, Philadelphia, Pa.
DR. ROBERT H. WILHELM, 4537 Spruce Street, Philadelphia, Pa.

NECROLOGY.

Mr. Robert Anderson, Lansdowne, Pa.
Mr. Richard Greenwood, Frankford, Phila., Pa.
Mr. Charles H. Parkin, Cleveland, Ohio.
Mr. E. D. Williams, Philadelphia, Pa.
Mr. Henry W. Wilson, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

ARENDT, MORTON. Storage Batteries. 1928.
Ausführliches Handbuch der Photographie. Band II, 4 Teil; Band IV, 1 Teil. Two volumes. 1928.
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LAWRIE, JAMES W. Glycerol and the Glycols. 1928.
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PAPESCH, OTTO. Reifung von Bromsilbergelatine mit Ammoniak und Ammoniumkarbonat. Enzyklopädie der Photographie und Kinematographie, Heft 113. 1928.
Photographischer Notiz-Kalender für das Jahr 1928.
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SVEDBERG, THE. Colloid Chemistry. Second edition. 1928.

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Zeitschrift für physikalische Chemie. Namen-und Sachregister zu den Bänden 102–125. 1928.

BOOK REVIEWS.

"TOWARDS THE OPEN." By Henry C. Tracy with an Introduction by Julian Huxley. xx–257 pages, 6 x 8¼ in., cloth. New York, E. P. Dutton & Co., 1927. Price, $3.50.

Every one knows that we are living in "a new age" and most well-educated persons agree that its chief characteristic is its interest in science. Philosophy and metaphysics have lost something of their charm for the thinker of today. He prefers facts and theories which keep close to facts. Hosts of books are being produced in the attempt to explain the world according to scientific theories and to build upon the basis of such explanations, programs for the advancement of both the individual human being and society as a whole.

"Towards the Open," by Henry Chester Tracy, is a book of this type.

Mr. Tracy is an American, his early education was in connection with a college founded by his father at Anatolia, in the Near East, followed by biological studies at Oberlin College in this country and later engaged in experiments in education at the Williams Institute, Berkeley, California. He has spent much time out in the open.

"Towards the Open" has been written carefully. The author has gathered knowledge covering wide segments of science, psychology, sociology, pedagogy, philosophy and religion; and made this so compact behind the words employed that entire sentences glow with the brilliance of the author's mind, as an incandescent lamp wire may shine from the power shot through it.

While one is reading these pages he must call continuously upon his own background of information in many different fields:

The author's observations may seem at times overponderous, or again a trifle sententious to the reader accustomed to the style in which articles on scientific subjects are usually written. But when the hand of an artist is revealed one readily overlooks a tendency which in a writer less skilled would be set down as a mere fussiness in verbal structure.

The Introduction to "Towards the Open" is by Julian Huxley. He premises that society is an organism in which coöperation and competition go hand in hand in what Morley Roberts calls a "hostile symbiosis."

"In so far as we men live on the organic level," continues Huxley, "we too must live in competition, patent or latent, with each other. True that on the mental or spiritual level this need no longer be so, and we can attain to complete coöperation. But the roots of our life are still organic, our lives and our enjoyments depend upon material objects, which cannot interpenetrate, cannot be in two places at once; so that it is not likely, in any state which we can even dimly envisage, that society will emerge from this condition of hostile symbiosis.

"That being so, it behooves us to organize our society so that the symbiosis is more effective, the hostility further below the surface, the regulation more complete.

"To take but one example, the course of economic events is marked by a recurrent series of 'slumps' and 'booms,' both of them inimical to steady economic progress, social advantage, and happiness. Each automatically generates the other; and so far no one has found a method of regulating their excesses. Such latitude is unthinkable to the physiologist. Over-production within the normal body, whether over-production by a particular gland, or the over-flooding of the blood with sugar released from store, is at once and automatically checked, and the normal balance preserved within astonishingly narrow limits."

The book has three parts as follows:

Part I Individuals as Social Units: Life: A Parenthesis; Significant Persons; Significant Societies; Aristogenic Evolution; Eugenics as a Personal Concern; Ethics and Population.

Part II Individuals as Organic Facts: Individuals as Organisms; Organisms as Perfectible; Socialized Ends; Schooling for a World-Stage; A Life of Education; A Critique of Satisfactions.

Part III Individuals as Creative and Spiritual: Concrete Personality; Artistic Intuition; A Unifying Principle; Humanism as Tolerance; A Natural Mysticism; Towards the Open: A Conclusion.

We quote a few paragraphs from the last chapter:

"Beginning with the cell, all of life is a fresh adventure for that cell as individual in the natural world. First, it inherits from two lines of parentage and not from one. Thus the sting of its encounter with an aline lineage is present from the start; was the condition of its development as embryo; remains operative in its invisible genes. Sting and stimulation continue all through the enlarging life, and are, literally, its destiny taking form. Until birth, and for some time afterwards, this spur and drive upon the primal inertia remains in the unconscious, under physiological control. Before a year is over the clash of heredities and the string of contacts are being recorded in the psyche. After that the world is a continual challenge to the conscious self. Innate tendencies are being rounded. New-waked impulses have to be tried on a surrounding envelope of persons and things. Each day is an adventure, and each day, to such an individual, is new. As the cells mature and become functional, new faculties awake, so that the newness is cosmic in its range of perception; space, time and matter are reflected in the 'microcosm.'"

"To be aware of one's social-natural environment in its changing multiplicity, to read beneath the surface-ripples significant movements of thought rather than a medley of accidents, is to bring that environment, as far as may be, under voluntary control. There is no known limit to what one poised centre of awareness—one person detached from the wheels of obsession but not from sympathetic intelligence—can do in and for a group."

"It is at this point that the science of the individual becomes also the science of society, of the group. Groups have been driven, as in the Children's Crusade, by undirected energy and by impulses that may have been fine enough in themselves. There are modern crusades equally stupid, and the Great Stupidity is to be ruled by a fraction of one's mind."

The position taken by Mr. Tracy is in the main a review of modern educational processes and a plea for their improvement. As such it is not subject to criticism from the point of view of the physical sciences. We may do well to ignore any minor criticism involving points which do not affect the argument.

We are not sure that the author would agree with our opinion that his entire thesis is best summed up in his chapter "A Life of Education." At any rate we believe we can give no clearer or fairer idea of the purpose disclosed in this book than to quote from that section the four remedial propositions laid down by Mr. Tracy. They are as follows:

"There are certain things for the individual, and we may say to him and to his parents that he can get them, in spite of the schools. Let him pursue them and forget his grades. They are:

"First, his own individuality, with a refusal to receive the rubber stamp.

"What does this mean to me? I should have him ask himself of every new exercise, idea, detail of material assigned. By asking that question continually, and refusing to consider what the teacher or text seems to want it to mean (except as one among several alternatives) he may keep alive his power of discrimination. His parents can help him to keep that alive. It is their one resource under the present calamity that has overtaken the schools;

"Second, a grounding in the principles of humanized science, as a prophylactic against erratic philosophies, conjectural nonsense, incantations and hocus-pocus of every sort. He may have to do the humanizing himself. Let those rare parents who are free from mental infatuations, and the few enlightened teachers who can discriminate between the sane and the unsound, consider what a problem he has there. It will tax their mental resources to keep pace with his problem, even while he is in his teens;

"Third, stimulation. He needs it. That is what literature is for, with art and music, letterless forms of the life-rhythms. The child knows best what he responds to. The adult may help him direct that response: into reflection, composition, into any active effort that converts it into the stuff of his life. The stimulation is commonly there, but not the guidance. This point leads directly to the next individualistic objective, which is,

"Fourth, expression; usually called self-expression. In reality it is the breaking crest of a wave that started eons ago, or in eternity. It is trivial in proportion as it expresses merely the self—a thing of the moment. It becomes more than that as it is subject to a deeper control. That control should begin to find its vehicle very early in the life of a child. It does find it: self-expression begins in look, laughter and voice; it ends in supreme genius or in simple, genuine acts of everyday life. The problem is to find what is genuine—or, as some would put it, expresses the 'deep self.' Hardly anything in mechanized education either evokes that or recognizes it when it comes.

"This last, then, is the concrete aim of education, so far as it concerns the individual. But note that it connects immediately with the social end of it all; for what is society but a collective organization designed to favour the genuine expression of its members, their deep selves, for the advantage and satisfaction of all."

JOHN W. STOCKWELL.

ELECTRIC WINDERS. A manual on the design, construction, application and operation of winding engines and mine hoists. By H. H. Broughton, M.I.Mech.E., M.I.E.E., etc. 402 pages, illustrations, plates, tables, quarto. New York, D. Van Nostrand Company, Inc., 1928. Price, $15.

Among the multiplicity of specialized types of machines which are employed in the mining industry, the mine hoist and its component elements, the develop-

ment of a very special form of elevator peculiar to that industry, apart from its fundamental principles, embraces many equally special problems of design. In point of magnitude, it may be noted, the speeds and power requirements of these hoists attain such values as 4,000 feet per minute with a rated motor-capacity of 5,000 horse power, dimensions which far transcend those of elevators of familiar type.

Under the title "electric winders" the author has gathered a comprehensive collection, it may fairly be said, of practically all that pertains to the mechanism of the hoisting plant and the conditions that affect its design. No other motive power than the universally adaptable electric motor is considered, public power-current being well nigh universally available. Failing of such a source of current, the author in a chapter on power supply, discusses applicable methods of power generation. As in any power consuming project, an essential preliminary is an analysis of the "duty cycle" of the winder or a graph of the power required plotted against time. Matters of this kind and the variety of arrangements of the mechanisms which may be employed in meeting assumed and derived specifications of performance are fully analyzed and illustrated by many diagrams and drawings of apparatus and details. The multiplicity of problems of mine-hoisting conditions, the detailed analyses of those problems, and the methods of meeting them are described at generous length by deduction from mechanical principles and an unusually copious collection of their numerical application to the details of systems taken from actual practice. The author evidently enjoys unsurpassed facilities for securing data on current practice of hoisting in English and African mines, and a rare capacity for its presentation in a book of encyclopedic character.

LUCIEN E. PICOLET.

"THE NEW UNIVERSE" (AN OUTLINE OF THE WORLDS IN WHICH WE LIVE). By Baker Brownell, Professor of Contemporary Thought, Northwestern University. x–455 pages, 6¼ x 9¼, cloth. New York, D. Van Nostrand Company, 1926. Price, $4.

Dr. Brownell in a Note at the beginning of the volume says:

"The universe brewed in the kettle of this book presumes an interested and rather well acquainted taste for current problems and ideas. . . . For most persons Chapter II will be the peak of difficulty for the entire book."

This Chapter II is addressed to "The Components of the Material World: the relativity of space, time and motion. Einstein. The electrical structure of matter. The quantitative basis of the elements. The transmutation of the elements. Conservation. The quantum theory of energy." These 25 pages contribute the most to the thought of those who have "a taste for current problems." The remainder of the volume is the unfolding of the author's astute and beautifully fluid cogitations about the world and phenomena, highly colorful and literary.

Baker Brownell has a style somewhat like that of Henry C. Tracy in "Towards the Open." Both authors are students of science and philosophy and both have the skill to use words and phrases as the painter does his colors, in entrancingly contrasting tones and cadences. Here is an example:

"To accept the scientific world of atoms, electrons, vibrations, laws of

gravity and the like, as in real relation to the sensations of sound or color through which we observe them, is a coup d'etat of common sense that no amount of rational elaboration can verify."

The author evidently is much impressed with the idea of reality. He declares:

"The problem of the world in general is a problem of the real, but reality is no terse word set up for definition. . . . It is everyone's problem and the meditations on reality inherent in it inhabit every mind. . . .

"The search for a field of reference whereon the shifting elements of human experience, things, contingent events may be placed and coördinated has led many a philosopher to labor on this world in general with a good deal of hope. It is a problem in philosophical location, and the classical demand for external absolutes, ultimate organizations, supreme laws and monitors is inspired by the same locative needs that move the physicist in another field to demand absolute space, time, an absolute 'now,' a fixed world stuff. . . .

"Where reality is the problem, truth, an amanuensis, and knowledge, a maid servant, are not first in interest. Real things are many; we may know what they specifically are; we may find truths and diverse things. But the reality of them is not many: no substance, says Spinoza, is divisible. Reality is gratuitously here: but no one can say what it is. It is the world in general. . . .

"Reality leans against us like a wall of wind. . . .

"We must give up the idea that science can incorporate all reality in itself, and then the antithesis between the worlds of description and appreciation, between mechanics and ends will disappear (suggested to Brownell by Dewey)."

But we find that, after all, Dr. Brownell does not deal with one universe as a unified reality. He has the thought about reality nicely distinguished. It is in three compartments: the world of action, the world of spirit and the world of science.

"Across the diverse fields of discourse, of worlds of action, of spirit, of science, oneness is more difficult to trace and even more important," he explains. "The worlds bounce apart like tennis balls; systematic unities break down; external ultimates are futile; and what oneness there may be among them it is clear is not like these. . . .

"To say that 'worlds' of science, of the spirit, of action are dimensions of the universe is more a metaphor than an accurate proposition. But the world in general can only be suggested, and dimensional analogies will come as near to saying it, no doubt, as all the ghosts and legends and the trying of philosophers and scientists will ever come. The world may have dimensions, many of them, these at least are three."

Common thought, of course, supports this distinction between "the world of mind" and "the world of matter"; and many of the scholars of the day would follow Dr. Brownell with complete agreement in such discourses as this:

"The tools that science uses to describe this world cannot apply to being, and the scientist is right in refusing to treat as a descriptive problem, what primarily is not amenable to descriptive method. . . .

"What are the tools of science? With what instruments does it approach the world? They are different, it is sure, from the ways of the spirit. The one is intuitive and agglutinative; the other is rational and classificatory. The one realizes the self in things; the other distinguishes the self from things. . . .

"By hypothesis science is finite. It creates the finite, as it were; it selects the finite factors of the world from a chest where many other things may be available. That is all that reason and sensation are equipped to do."

From the title "The New Universe," one might be led to look for an effort to view all phenomena from one field of reference. The book does not do this. Perhaps the author shows his wisdom in not attempting to do it.

Certainly this volume commands the attention of all those who wish to keep alive to the problems of the day. It rewards the hunger for careful and correct discussion, clear thought, beautiful imagery.

The work is built as "Book I, Studies in Matter, the world as scientific fact; Book II, Studies in Social Policy, the world of human conduct and practical action; and Book III, Studies in Personal Values, the world of appreciations and spiritual interests." An Appendix offers a "Table of Key Ideas" (merely a summary of the contents of each of the 17 chapters). The list of References is complete and well arranged.

JOHN W. STOCKWELL.

A TEXT-BOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.Sc., F.I.C. Volume vi, Part 1. Nitrogen, by Edmund B. R. Prideaux, M.A., F.I.C., and Herbert Lambourne, M.A., M.Sc., F.I.C. 242 pages, illustrations, 8vo. Philadelphia, J. B. Lippincott Company, 1928.

The element nitrogen has perhaps attracted more attention in connection with the development of industrial chemistry than any other in the list. Its important relations to living tissues, and, in striking contrast, to high explosives, have caused a very large amount of research to be given to it in all great nations. In some respects it is a very remarkable element for in the free state it shows so little chemical activity that it seems to be allied to the group now called "the noble gases," but it is capable of developing high affinity, and many compounds showing great contrasts in properties can be found in the descriptive text books.

Nitrogen belongs to group five of the Periodic system, the members of which range from a typical non-metal to a typical metal. Nitrogen is associated in its special group with several elements capable of forming highly poisonous compounds, but the type of poisoning that these exhibit is different from that exhibited by most of the poisonous nitrogen compounds.

The book in hand discusses the general character of the members of group five, divided into two sub-groups, one beginning with vanadium and ending with a radium derivative, the other, the familiar series, nitrogen phosphorus, arsenic, antimony, and bismuth. The greater portion of the book is devoted to descriptions of the important nitrogen compounds. The many nitrogen derivatives in organic chemistry are, of course, not included. About thirty pages are devoted to the nitrogen-fixation. Since the series to which this volume belongs is descriptive chemistry, the important question of nitrogen-fixation is not treated extensively. For such treatment we must turn to the comprehensive manuals now available. The general make-up of the volume is, of course the same as that of the other members of the series now so well known to chemists, the printing and paper being of high class, the references to the literature extensive and in detail. A commendable feature of the reference is that the year as well as the volume is always given when the two data are available. Physical data are given in great amount

and there are brief but useful and interesting notes on the history of the compounds, and on the chemical principles that are involved.

HENRY LEFFMANN.

A TEXT-BOOK OF INORGANIC CHEMISTRY. Edited by J. Newton Friend, D.Sc., F.I.C. Volume X, The Metal-Ammines. By Miss M. M. J. Sutherland, D.Sc., F.I.C. 260 pages, illustrations, 8vo. Philadelphia, J. B. Lippincott Company, 1928.

The reviewer cannot avoid a preliminary allusion to the somewhat unusual instance that this book on a very highly specialized department of organic chemistry is written by a woman. As to what women will accomplish in science and politics, now that these opportunities have been so freely opened to them, is still not certainly demonstrated. Men generally have been skeptical as to the results of the complete enfranchisement of women and the unrestrained opportunities for the education in association with men. Heine said sarcastically, "when a woman writes a novel she has one eye on her work and one eye on some man. There is only one exception to this, the countess Ida Hahn-Hahn. She has only one eye."

The reviewer, however, does not make any such insinuation as to the merits of the author of this volume, whose degree gives ample evidence of thorough preparation for the work. The usual expressions of obligation to others are given in the preface. The descriptive portion is preceded by chapters on general principles and valency. Considerable space is given to the general character of the compounds which as might be expected are very numerous and many very complicated. Their intricate structural formulas and spatial relations are presented by a large number of clear diagrams. The book, therefore, represents an enormous amount of study of the literature, careful sifting of it and comprehensive, vivid arrangement. It takes its place in the series to which it belongs and is worthy of every praise. A work so highly specialized will find only a limited number of readers but these will be greatly aided by having the data collected in a compact, easily accessible form, and presented in excellent type and printing. The volume contains also the very useful table of the dates of issues of leading journals.

HENRY LEFFMANN.

STORAGE BATTERIES, THEORY, MANUFACTURE, CARE, AND APPLICATION. By Morton Arendt, E. E., Fellow American Institute Electrical Engineers, Assistant Professor of Electrical Engineering, Columbia University. v–285 pages, illustrations, 23 x 15 cm., cloth. New York, D. Van Nostrand Company, Inc., 1928. Price, $4.50.

When the storage battery first became a commercial possibility, much was expected of it as an equalizer of the fluctuating loads carried by central stations. Factors of cost and upkeep at that time militated against its general adoption in that service. In the course of time, progress in the design of power-production equipment has rendered less insistent this means of improving the load factor. Forced draft by which steaming capacity is quickly increased, and the heavy overload capacity of engine and generator have done much to carry the load over the peaks. Further, where stations intercommunicate over large areas, the load factor is more favorable than in the isolated stations of an earlier day, and the

need of storage batteries in that service may be said to have been eliminated. To a restricted extent its use in that service survives, but in greater part, the industry has grown in meeting the demands of other applications, some of which are familiar to everyone, as for example, to the starting and lighting system of motor cars, electrically-propelled trucks and the now widely used electric lighting of steam railway cars, and many other equally important auxiliary functions.

The technique of storage battery engineering is of highly specialized character, and in order to successfully cope with its problems, a keen appreciation not alone of the electrochemical features of the subject but also of its constructive features is requisite. It is upon a practically useful plan of this sort that the present treatise is designed. First the general theory is taken up, then lead plates, factors influencing capacity and efficiency, the lead storage cell, its component parts and assembly, installation, operation and maintenance. This is followed by considerable space on the Edison nickle-iron-alkaline cell, and finally chapters on storage battery testing and on storage battery applications. The subject-matter throughout is adequately illustrated by half-tones and many illuminating diagrams of characteristics and performance. The inclusion of many practical details of manufacture, as precautions to be observed in lead-burning and types of construction are notable features. The work is thorough and exceedingly consistent in the treatment of its diversified contents.

LUCIEN E. PICOLET.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 290. Water-Pressure Distribution on a Seaplane Float, by F. L. Thompson. 15 pages, illustrations, plate, quarto. Washington, Government Printing Office, 1928. Price, ten cents.

The investigation reported herein was conducted by the Committee at the request of the Bureau of Aeronautics, Navy Department, for the purpose of determining the distribution and magnitude of water pressures likely to be experienced on seaplane hulls in service. It consisted of the development and construction of apparatus for recording water pressures lasting one one-hundredth second or longer and of flight tests to determine the water pressures on a UO–1 seaplane float under various conditions of taxying, taking off, and landing.

The apparatus developed was found to operate with satisfactory accuracy and is suitable for flight tests on other seaplanes.

The tests on the UO–1 showed that maximum pressures of about 6.5 pounds per square inch occur at the step for the full width of the float bottom. Proceeding forward from the step the maximum pressures decrease in magnitude uniformly toward the bow, and the region of highest pressures narrows toward the keel. Immediately abaft the step the maximum pressures are very small, but increase in magnitude toward the stern and there once reached a value of about 5 pounds per square inch.

THE MODERN CALORIMETER. By Walter P. White, Ph.D., Physicist in the Geophysical Laboratory of the Carnegie Institution of Washington. American Chemical Society Monograph Series No. 42. 194 pages, 16 illustrations, cloth 8vo. New York, The Chemical Catalog Company, Inc., 1928. Price, $4.

According to the author this book was produced as an experiment. He has labored in no small measure to classify the various factors introducing sources of error; to treat in a thorough manner the methods involved in calculating these errors and to furnish a critical analysis of the applicability of these calculated errors to the desired precision in calorimetric measurements. A considerable portion of the book consists of the application of these various error calculations to operation of Joule's twin calorimeters, the ice, vacuum-walled, adiabatic, aneroid (fluidless) and last but not least the common type of calorimeter so well known to most of us.

An extensive dissertation upon the source and magnitude of possible errors comprises the first half of the book. This is followed by a discussion of methods in general and then by chapters on particular methods and apparatus in which the manipulation of several types of calorimeters are considered in more detail. The final chapter on "Application to Calorimeter Design and the Planning of Installations" is particularly valuable. In it are cited the required type of apparatus and necessary precautions corresponding to a desired degree of precision.

Primarily "The Modern Calorimeter" is for the perusal and study of those engaged in calorimetric measurements which are not of a haphazard or casual nature. It should prove to be a valuable aid in determining the absolute as well as relative precision obtained in calorimetric determinations. To anyone not versed in the technic of calorimetry this book will be laborious to read. Yet, those desiring a general idea of the scope of inventive genius and an unbiased evaluation of its own accomplishments in the field of calorimetry will do well to glance through this volume, even in a casual way.

The author's masterful treatment of the subject reveals an intimate, theoretical and working knowledge of the same and the opinion is expressed that such a pioneer attempt is to be greatly appreciated.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AËRONAUTICS.

Report No. 308. Aircraft Accidents Method of Analysis. Report prepared by Special Committee on the Nomenclature, Subdivision, and Classification of Aircraft Accidents. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1928, price, ten cents.

This report on a method of analysis of aircraft accidents has been prepared by a special committee on the nomenclature, subdivision, and classification of aircraft accidents organized by the National Advisory Committee for Aëronautics in response to a request dated February 18, 1928, from the air coördination committee consisting of the Assistant Secretaries for Aëronautics in the Departments of War, Navy, and Commerce. The work was undertaken in recognition of the difficulty of drawing correct conclusions from efforts to analyze and compare reports of aircraft accidents prepared by different organizations using different classifications and definitions. The air coördination committee's request was

made "in order that practices used may henceforth conform to a standard and be universally comparable." The purpose of the special committee therefore was to prepare a basis for the classification and comparison of aircraft accidents, both civil and military.

CHEMICAL ENGINEERING CATALOG. Thirteenth annual edition, 1160 pages, illustrated, quarto. New York, The Chemical Catalog Company, Inc., 1928. Prices adjusted to special conditions as indicated in the volume.

This publication has been noticed as it appeared in the issues of the Journal and it is necessary here only to record that the present edition maintains the character of the work as established in its earlier publications and constitutes a very valuable summary of the chemical engineering manufacturing in this country. The classified directory has been further enlarged and contains the listings of more than 2000 manufacturers. Its use to those engaged in purchasing the materials of chemical engineering is very great and the manner in which the publishers keep in touch with those who use the book is highly commendable. The information bureau maintained by the publishers for many years has been doing excellent service to its customers. More than 2400 books are listed in the technical and scientific books section. Information is also given concerning the American Chemical Society's Monographs. The book is printed in excellent form and very liberally illustrated. The present edition has a new feature in a Trade Name Index of nine pages. The individual pages give full and detailed information concerning the products of the firms using the space and these pages should always be consulted. H. L.

PRACTICAL TELEVISION. By E. T. Larner, Engineering Department, General Post Office, London; Associate of the Institution of Electrical Engineers; Formerly Lecturer in Electrical Engineering at the London County Council (Hackney Institute), with a foreword by John L. Baird. 175 pages, illustrations, 22 x 14 cm., cloth. New York, D. Van Nostrand Company, Inc., 1928. Price, $3.75.

In the early nineties we had the first display of the "Kinetoscope" the forerunner of the modern cinema. Those who witnessed its performance through the binocular eye-pieces can testify to the excellence of the reproduction of the scenes displayed. Now, after an interval of thirty-five years, comes "television," the production of the image of a distant view transmitted electrically by wire or by wireless. Television is yet far from the practically usable state of the kinetoscope in its day, but its possibilities have been demonstrated, and the history of the cinema and other epoch-making inventions which have become commonplace bespeaks a successful evolution for television.

The striking achievement of the transmission of pictures by telegraph is something of an old story now. In that process, the time-lag of the selenium cell which it employed did not present the same obstacle as in television where instant response is essential; and the best promise of the latter appears to have come with the application of the modern photo-cell whose response to the action of light is many times more rapid. No extravagant claims are made for television by *bona fide* exponents of the art, but the goal of its promoters is to receive simultaneously sound and vision by radio. The activity in the effort to attain

that end is indicated by the recent announcement that nine radio stations are now broadcasting television on experimental schedules.

In the present volume, the author deals with the principles of television and the manner in which they have been utilized in the evolution of a practical moving-image transmitting apparatus. The history of the subject is outlined, and an account is given of the more modern researches in Europe and in the United States in which is included the work of Jenkins and Alexanderson. Considerable space is allotted to a discussion of the properties, construction and performance of the selenium and the modern photo-electric cell, but little more than passing mention is accorded the neon light. Considerable stress is laid upon the value of the cathode ray oscillograph tube for the successive illumination of different points of a fluorescent screen with no appreciable time-lag. The work with its ninety-seven excellent illustrations and diagrams constitutes a description of rare merit of what has already been done in the technique of television and what may be expected of it in the future.

LUCIEN E. PICOLET.

COLLECTION DE SUGGESTIONS SCIENTIFIQUES PUBLIÉE SOUS LA DIRECTION DE LÉON BRILLOUIN. Fascicule I. Quelques suggestions concernant la Matière et le Rayonnement par Th. Coppel, Georges Fournier et D. K. Yovanovitch. 46 pages, 22 x 14 cm., paper. Price, 4 francs 50. Fascicule II. Sur la Théorie des Quanta de Lumiere par Al. Proca. 96 pages, 22 x 14 cm., paper. Price, 9 francs. Paris, Librairie Scientifique Albert Blanchard, 1928.

The present-day investigator in physical science has a much easier task in the search for precedent among the classics of the science than his predecessors of several decades anterior. Numerous monographs by authors of note which formerly were available only in periodical literature have become accessible by the publication of series on several divisions of physical science which cover a wide variety of topics. The present publishers have gone a step further in this movement by the issue of a unique series which cover what may be termed "classics of physical science in the making" rather than the work of already well-known authors. An extract of their foreword defines their object:

"Nearly all the daring ideas upon which the actualities of science are founded have seemed—the day they were first disclosed by some unknown investigator—fantastic, arbitrary, and even a bit absurd. The history of great discoveries offers the distressing spectacle of an extraordinary wastage of effort; what ideas, what suggestions scattered in inaccessible publications, forgotten or lost forever with their authors. What, for example, is more tragic than the lot of the notes of Carnot on the principle of equivalence, unpublished during his lifetime, lost, and a half century later found by chance after they had ceased to represent more than historic interest? It is a fact that those ideas which have most profoundly influenced the progress of science have been relegated at the outset to the category of fantastic and absurd lucubrations. Why not then make profitable use of this lesson of history? Why not make a systematic search among ideas which appear eccentric and strange, at first, for suggestions of theories and applications of tomorrow? The present collection has for its very object to facilitate such research. For a given epoch, it aims to become the mirror of organized fantasies of scientists, a sort of library of new conceptions in which investigators

may seek inspiration and which the reader interested in matters of science will likewise consult with satisfaction."

Of the two initial contributions to the series, the first examines, with the freedom of thought permitted by an avowed speculative analysis, the fundamentals of the nature of matter and of radiation. Under this general title the authors review the modern conceptions of space, time and matter. In particular they dwell especially upon the quantification of space and of time, and further, upon a quantified universe. The idea of continuity, the Bohr principle of correspondence, β- and γ-rays, and the structure of the electron receives attention.

The second volume, on the theory of light quanta, aims to diminish some of the difficulties which are encountered in reconciling the two principal theories of optics, the wave theory, and that of light quanta. To that end, light quanta are considered in a medium devoid of all matter, the mechanism itself of the emission being disregarded. The structure of light quanta is examined in detail, its energy, and the general relation between this energy and the frequency are calculated. The phenomena of interference are considered and the manner in which the type of quantum adopted is applicable to an explanation of interference is discussed.

The rational and deductive character of these first volumes promise well for the value of the unique departure in scientific literature of the Collections de Suggestions Scientifiques. L. E. P.

ELEMENTARY LABORATORY EXPERIMENTS IN ORGANIC CHEMISTRY. By R. Adams, Professor of Organic Chemistry in the University of Illinois, and J. R. Johnson, Ass't Professor of Organic Chemistry in Cornell University. 305 pages, illustrations, 8vo. New York, The Macmillan Company, 1928.

Though termed elementary experiments, most of the procedures described in this volume would have been regarded years ago as decidedly advanced, yet they are intended for first semester students, whether specializing in chemistry or merely seeking knowledge as accessory to professional study or practical application. Many interesting and important processes are described in full detail and a series of questions posed that cover the theoretical and some of the practical data concerning the procedures. Several procedures seem rather risky and while it is, of course, necessary to select from all fields in order to give the student a comprehensive training, yet less dangerous examples might have been culled out. However the work is presumed to be carried out under careful supervision and special cautions are given in the text for all the dangers.

The descriptions of the procedures are printed on sheets that can be easily detached and pasted in a note book, so that the book itself need not be kept at the operating table. Students are much too liable to keep their books where they work and thus get them stained and often seriously injured.

HENRY LEFFMANN.

PUBLICATIONS RECEIVED.

Théorie Ionique de l'Excitation des Tissus Vivants, par le Professuer Docteur P. Lasareff. 240 pages, illustrations, 8vo. Paris, Librairie Scientifique Albert Blanchard, 1928, price 40 francs.

Quelques Suggestions Concernant la Matière et le Rayonnement, par Th. Coppel, Georges Fournier, D. K. Yovanovitch. 46 pages, illustrations, 8vo. Paris, Librairie Scientifique Albert Blanchard, 1928, price 4.50 francs.

Sur la Theorie des Quanta de Lumière, par Al. Proca. 96 pages, illustracions, 8vo. Paris, Librairie Scientifique Albert Blanchard, 1928, price 9 francs.

Handbuch der Experimentalphysik, herausgegeben von W. Wien und F. Harms. Band 13, 2 Teil, Physik der Glühelektroden von Prof. Dr. W. Schottky und Dr. Ing. H. Rothe; Herstellung der Glühelektroden von Dr. Rer. Techn. H. Simon; Technische Elektronenröhren und ihre Verwendung von Dr. Ing. H. Rothe. 492 pages, illustrations, 8vo. Leipzig, Akademische Verlagsgesellschaft m.b.H. 1928, price 46 marks.

The Engineer, His Work and His Education, by Robert Lemuel Sackett, C.E. 196 pages, portrait, 8vo. Boston, Ginn and Company, 1928, price $1.40.

National Advisory Committee for Aëronautics. Thirteenth Annual Report, 1926. 510 pages, illustrations, tables, diagrams, quarto. Technical Notes, No. 297, Preliminary report on the Flat-top Lift Curve as a Factor in Control at Low Speed. 10 pages, diagrams, quarto. No. 298, The Determination of Several Spray Characteristics of a High-Speed Oil Engine Injection System with an Oscilloscope, by Chester W. Hicks and Charles S. Moore. 11 pages, plate, diagrams, quarto. Washington, Committee, 1928.

Great Britain Department of Scientific and Industrial Research. Radio Research Special Report No. 7. Wireless Observations During the Eclipse of the Sun, 29th June, 1927. 25 pages, plate, diagrams, 8vo. London, H. M. Stationery Office, price 1s. 3d.

Western Railways' Committee on Public Relations. Railroad Facts No. 6, A Yearbook of Railroad Information, 1928 Edition. 94 pages, illustrations, 8vo. Chicago, Committee, 1928.

Chemical Engineering Catalog. Thirteenth Annual Edition, 1928. 1107 pages, illustrations, quarto. New York, Chemical Catalog Company, Inc., price $10.00.

Electric Lines and Nets. Their Theory and Electrical Behavior, by A. E. Kennelly. 2d edition. 426 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc., 1928, price $5.00.

Elementary Laboratory Experiments in Organic Chemistry, by Roger Adams and John R. Johnson. 304 pages, illustrations, 8vo. New York, Macmillan Company, 1928.

Heaviside's Electrical Circuit Theory, by Louis Cohen, Ph.D. First Edition. 169 pages, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc., 1928, price $2.50.

Technical Books of 1927. A Selection. 28 pages, 16mo. Brooklyn, Pratt Institute Free Library, 1928.

CURRENT TOPICS.

An Ultra-Microscope of Small Dimensions. A. TURPAIN AND R. BONY DE LAVERGNE. (*Comptes Rendus*, June 11, 1928.) When a beam of rays of light falls on a transparent sphere parallel to a diameter, the size of the emerging beam depends upon the index of refraction of the material of the sphere. For a sphere filled with carbon bisulphide the diameter is only a third as great as for a sphere of water, while for a diamond the diameter is reduced to a point. By employing spheres of glass 2 or 3 mm. in diameter the authors succeeded in dispensing with the cumbrous illuminating devices used on ultra-microscopes so that the light from an electric lamp one cm. in diameter is sufficient. In addition high magnifications became possible along with other improvements of technique. "Under these conditions we were able to expose ultra-microscopic preparations to very strong magnetic fields and to convince ourselves that the particles in Brownian movement were not uninfluenced by the magnetic field provided it was brought to bear in a suitable way." G. F. S.

The Utilization of the Thermal Energy of the Sea. GEORGES CLAUDE AND P. BOUCHEROT. (*Comptes Rendus*, June 4, 1928.) Claude, the distinguished French engineer, made public within the last few years a proposal for obtaining energy from tropical waters by taking advantage of the difference of temperatures that exist at different depths. Objections were raised to the feasibility of the project and to meet them the method has been tried out under conditions approaching those of practice and on a partly industrial scale.

Two tanks, each holding 100 cu. m., are at the same level and situated below the turbine to be operated. Both hold water taken from the Meuse River. In one the temperature is raised about 20° C. by steam or otherwise. The warm water is pumped up 9 m. to a chamber where it is freed of dissolved air. It then passes on at the same level to a space in which it evaporates under the greatly reduced pressure. The water cooled by evaporation flows down to the original lower level through a pipe and is thence discharged. The water vapor produced by the evaporation of a part of the warm water goes to drive a turbine and afterwards passes into a chamber where it is condensed by cold water from the second tank at low

level which also has been pumped up 9 m. and freed of gases. The turbine has a rotor one meter in diameter. Its normal capacity is 50 kw. but it is capable of giving 60 kw. To it a dynamo is coupled. In a test made May 19, 1928, the warm water cooled from 33° to 29.7° C., and the cool water rose from 12.8° to 16.2°. The turbine made 5600 r.p.m.; the dynamo developed 59.4 kw., of which 11 kw. were used for pumping and 7 kw. in getting rid of the dissolved air. Thus 41.7 kw. were left available. This is 69 per cent. of the output. This shows that the auxiliary operations do not absorb the entire power of the dynamo as was objected.

At the end of the presentation of the paper H. LeChatelier said: "If the final installation in Cuba is to become a reality, as everything now seems to indicate, this day of June 1 will remain historic in the archives of industry. This is the first time that an actual steam machine has been seen running with a difference of temperature of 10° only. All the experts regarded the thing as impossible.

"For a long time people have been concerned with the future of civilization on the earth at the time when coal mines shall be exhausted. It was thought that we should end by discovering some other process for utilizing solar energy, but trials made with solar engines or with turbines operated by the tides required the investment of so much capital that finally such solutions came to be regarded as economically impossible. The heat accumulated in sea water, while it is not as concentrated as that stored up by vegetable life in the Coal Period, does, however, present infinitely more advantages than all other previous solutions of the problem." He spoke of the success attained in maintaining the vacuum in the machine, of the ease of starting it or slowing it down. There remains the difficult task of putting in place the long pipe that is to bring up from the depths of the sea the cold water for condensation.

In addition to his engineering work Claude was this spring a candidate for election to the Chamber of Deputies in the second district of the department of Seine-et-Marne (Fontainebleu). His campaign was conducted in a unique way. *Le Matin* of April 12 gave an account of his methods in an article written by Stéphane Lauzanne. The place was a dance hall on the edge of the Forest of Fontainebleu. There were no benches but boxes had been brought in to serve as seats, which were chiefly occupied by women. These formed a large part of the audience though they do not vote in France. "A door opens. A man appears, astonishingly young under his curly gray hair, and the audience stiffens with respect mingled with curiosity. George Claude begins his address. 'Ladies and gentlemen, by science life can be directed toward prosperity. I shall therefore talk to you about science. It is a

thing that I know. For once you are going to hear a candidate on something that he knows.' First he spoke about liquid air in the production of which he has played so large a part. He then showed a series of experiments. His five hundred auditors broke into applause. He appealed to his audience to rely more on science and less on politics for the return of prosperity to their country. 'Science will aid to bring peace also, for she will make France stronger. I have a horror of war. I believe there are Germans who have the same horror.' He was heckled and flung back 'That doesn't suit you what I said then? Very well. Don't vote for me. You know I don't care a hang about being elected.'" In the first election he received 9338 votes against 9183 for his nearest opponent. It was necessary to ballot again as no candidate received a majority of all votes cast. At the second election he received only 6355 votes. The man who was next to him at the first election was elected as he received 6614 votes. G. F. S.

New Precision in Cosmic Ray Measurements; Yielding Extension of Spectrum and Indications of Bands. R. A. MILLIKAN AND G. H. CAMERON. (*Phys. Rev.*, June, 1928.) Up to the present time there has been only the most general agreement in the measurements made on cosmic rays by different observers. For example, at high altitudes Millikan and Bowen found a total discharge for an electroscope that was only one-fourth of that calculated from the curves of Kohlhoerster and Hess, and for Pikes Peak Millikan got a rate of production of ions seven times as large as that found by Swann for the same mountain. "Such differences are quite like those found, for example, in the early determinations of e/m which showed fluctuations of 100 per cent., but they cannot long be permitted." The authors, therefore, turned from the study of the variations of cosmic rays in relation to altitude, direction, geographical position and penetration to the development of better measuring instruments. They have produced an electroscope of spherical shape especially designed for use under water. Its walls are of steel .6 mm. thick so that its sensitiveness can be greatly enhanced by increasing the atmospheric pressure within it. Furthermore its capacity can be determined with high accuracy.

With a pressure of eight atmospheres within it the electroscope was about eight times as sensitive as the instrument previously used under water. It was used for a new series of studies of the penetration of cosmic rays into mountain lakes, Arrowhead Lake, elevation 5100 ft., depth 140 ft. and Gem Lake, elevation 9080 ft. and depth 225 ft. Though they differ so much in elevation and though one lake is 250 miles north of the other "as in the case of all

our former under-water work, when the rates of discharge are plotted against depth in equivalent meters of water beneath the top surface of the atmosphere, *the readings all fall upon a smooth ionization-depth curve.*" The curve indicates that the precision is 10 times as great as that of their previous submarine instrument, and hence important conclusions can be deduced from a consideration of the curve. (In what follows depth is reckoned in equivalent meters of water below the upper surface of the earth's atmosphere.) The rate of production of ions goes on diminishing as the electroscope is lowered into the water until a depth of 58 m. is reached. In previous experiments the decrease ceased at 25 m. "This means at once that our increased sensibility has brought to light very much harder rays than we had observed before." Again, the absorption coefficient of water for cosmic rays at a depth of 10 m. is .20 and a meter lower it has dropped to .11. This sudden change "at a depth of about 11 m. means that at that point a band of long wave-length, or of relatively large absorption coefficient, is dropping out and one of much shorter wave-length is left to cause the bulk of the ionization. The present measurements at least furnish indications that the cosmic rays consist chiefly of three bands for which the mean absorption coefficients are approximately 0.35, 0.08 and 0.04. Our shortest wave-length is now 0.00008 A, and the equivalent generating potential approximately 150,000,000 volts."

A calculation is made of the amount of energy brought by the cosmic rays to the earth. It is 3.02×10^{-3} ergs per sec. per sq. cm. This is about one-tenth of the influx of energy due to starlight.

G. F. S.

An Attempt to Add an Electron to the Nucleus of an Atom. W. D. HARKINS AND W. B. KAY. (*Phys. Rev.*, June, 1928.) Theory indicates that an electron is attracted by the nucleus of an atom. It may be that an ion can be driven into an atom with sufficient velocity to make it come within the range of the attraction of the nucleus. Electrons with an energy of 145,000 volts and a velocity of 1.9×10^9 cm./sec. were made to impinge on a surface of mercury that formed the anti-cathode in an X-ray tube. Mercury was selected because it can be separated almost completely from gold, the next lower element, and because a very small amount of gold can be detected in a large quantity of mercury. Should an atom of mercury receive an electron into its nucleus it should be thereby converted into an atom of gold. Though the stream of electrons bombarded the mercury for as much as 81 hours no trace whatever of gold was found. Had every ion lodged in a nucleus gold by the gram would have resulted. Certainly not one ion in a billion was

effective, though a billionth of a gram of gold could have been detected. G. F. S.

The Vibration of Bells. A. T. JONES. (*Phys. Rev.*, June, 1928.) This paper is the result of a study of the 10 bells of the Harkness Memorial Chime at Yale University. Little is known about the vibrations of bells. The partial tones of the same bell generally have inharmonious relations to one another, and the series of relative frequencies of the partials of one bell will not agree with the same series for another even if both bells came from the same maker. There is a concensus of opinion of some value that the first 7 partials should have frequencies with the ratios 1 : 2 : 2.4 : 3 : 4 : 5 : 6. It is to be noticed that all the numbers are integers except the third which is sometimes given as 2.5 instead of 2.4. The bells of the Harkness Chime had partials agreeing closely in frequency with the relations just given. The ratios about to be given are for the first 7 partials the averages of 10 bells but for the 8th, 9th and 10th for only 7 bells. The ratios are 1 : 2 : 2.4 : 2.98 : 4 : 5.12 : 5.92 : 6.56 : 7.6 : 8.12. For the Dorothea Carlile Chime at Smith College the same set of partials, except that the 8th is omitted, have these ratios,—1 : 1.58 : 2.05 : 2.95 : 3.45 : 4.72 : 5.17 : ( ) : 6.5 : 7.02. The graphic representation of the sounds from the Yale bells was obtained by using a microphone, amplifier and oscillograph with photographic registration. When the bell is struck there is a period of irregular motion lasting from .01 to .03 sec. This is succeeded by a considerable increase in amplitude and the arrival of a more regular type of vibration. In all the films good enough for analysis the 5th partial had a larger amplitude than any other, just after the end of the irregular motion. Records taken 3 sec. after bells were struck showed that large bells still had several important partials, while small bells possessed only one of any amplitude. G. F. S.

Michelson's Experiment Carried out in a Balloon and also on the Ground. A. PICCARD AND E. STAHEL. (*Jour. de Phys.*, February, 1928.) Dayton C. Miller, repeating Michelson's experiment on the drift of the ether past the earth, announced the existence on Mount Wilson of an ether wind of 10 km. per sec. This result is of fundamental importance because, if it is true, the very foundations of the Theory of Relativity are made to totter. It is consequently well that the experiment should be made under varying conditions and with different apparatus. The authors who are Belgians devised an apparatus much smaller that that used by Miller, yet having, according to their claims, greater accuracy, though in the

balloon temperature disturbances were considerable. Measurements were conducted at Brussels, in a balloon and on Rigi, in Switzerland. In no case do their results confirm those of Miller. It is, however, to be remembered that Professor Miller has had decades of experience in the conduct of this particular experiment, in which regard he has great advantage in respect to those who are criticizing his work. G. F. S.

The Existence of Intermetallic Compounds in the Vapor State. The Spectra of the Alkali Metals, and of their Alloys with Each Other. J. M. WALTER AND S. BARRATT. (*Proc. Royal Soc.*, A 782.) "It has been uncertain until recently, whether any of the many intermetallic compounds which have been established in liquid and solid alloys can persist into the vapor state, or whether they invariably dissociate into mere mixtures of the individual metal vapors. Volatile compounds have occasionally been suspected (*e.g.*, between magnesium and zinc) on account of the deposition of typical crystals of compounds during the distillation of an alloy of the two metals, but such evidence is so indirect that it carries little weight. The most promising way of approaching this question is by a study of the absorption spectra of mixtures of metallic vapors. The metals that are known to possess a measurable proportion of diatomic or polyatomic molecules in the vapor state invariably indicate this property by the appearance of bands in their absorption spectra. In fact, since it has been accepted that band spectra cannot originate from single atoms, the observation of such bands has become the most delicate test for the existence of association in the vapors." As a result of molecular weight determinations it has been held that the vapors of alkali metals are altogether monatomic, but this can no longer be maintained since these vapors show band spectra.

It has previously been shown that the mixed vapor of sodium and potassium has two band spectra and the conclusion has been drawn that there is an intermetallic compound existing in the state of vapor. Later by the same evidence it is clear that magnesium forms a volatile compound with each of the alkali metals. "In establishing the existence of an intermetallic compound by this method, the assumption is made that the spectrum of a mixture of two metals is purely additive unless a new type of molecule (i.e., of a compound) is formed, which is peculiar to the mixture." Before searching for band spectra in mixtures of metallic vapors the spectra of the several alkali metals were carefully examined. New bands were discovered for rubidium and cæsium. Then the spectra of each of the ten pairs of metals that can be grouped from lithium,

sodium, potassium, cæsium and rubidium were inspected for bands. No bands were attributable to lithium-sodium but each of these presents so many bands that the band of the compound may be hidden. All the other nine pairs showed bands, sodium-potassium having the most extensive. In general the bands lie close to the lines of the principal series of the two united atoms, but this is not true when lithium is one of the metals.

What fractional part of the total vapor is in the form of intermetallic compounds? Carelli and Pringsheim found that at 727° there are 2 per cent. as many diatomic atoms of potassium vapor as monatomic ones. For the same quantity Ditchburn obtained .9 per cent. Mitchell, by Victor Meyer's vapor density method got 5 per cent. The authors hold that at the boiling point of the metals these molecules containing one atom of each of the two constituent atoms make up one or two per cent. of the total vapor.

G. F. S.

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